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Rat Control on Hawaiian Sugar Cane Plantations

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This paper undertakes the task of bringing together our knowledge of the field control of rats in sugar cane fields. The four species of rats found in Hawaii are briefly discussed, giving some of their food and nesting habits. The control value of the mongoose is featured in contrast to adverse criticism sometimes heard. A study of rat populations in or near Hawaiian cane fields shows some of the factors controlling migration and distribution. The nature and extent of cane damage by rats are described. The more important rat-borne diseases in Hawaii are mentioned. Poisoning, when properly carried out, is shown to be the only practical and economical plan of rat control for large field areas.

The development of rat-control work in Hawaii is traced from its beginning in 1918 to the present, showing the successive roles of barium carbonate, strychnine, thallium sulphate and zinc phosphide as lethal agents with the effective concentrations of each. The employment of dry cereal baits is traced from its early use in direct poisoning in the form of torpedoes to the present prebaited method of feeding loose grain in feeding-station pans. The benefits to be derived from the use of oil attractants, sugar, and coloring agents to identify poisoned baits are discussed. Both the theory and field procedure in prebaiting work are reviewed in detail with some suggested modifications in technique.

Many questions pertaining to rat control have been subjected to cage and field experimentation. Prebaiting is shown to be a more efficient control method than direct poisoning. The problem of reinfestation of treated areas, the acceptance versus detection of poisoned bait, all receive attention.

The comparative efficiency of several rat poisons has been studied under the prebaited feeding-station method. Zinc phosphide proves to be fully equal to thallium sulphate as an efficient raticide. Yellow phosphorus is second in effectiveness, while forms of red squill, strychnine and arsenic are distinctly inferior.

The ever-present danger of secondary poisoning to other animals, when thallium sulphate is the lethal agent, is contrasted with the absence of this danger to pet animals from their eating rats poisoned by zinc phosphide bait. Sensible precautions to be observed while handling poisons are enumerated. A list of poisoned-bait formulas is contained in an appendix.

Contents

Introduction

The purpose of this paper is to review the early work which was done on the control of the field rat in Hawaii and elsewhere, and to treat in greater detail the results of more recent work.

The problem of rat control in cane fields never can be completely solved as long as large areas of wastelands, covered with a heavy vegetation, continue to supply large amounts of natural food. However, the results of our control measures in the fields have been so economically successful that we feel justified in recommending them.

The impact of the war necessitated substitutions in the poison formulas as well as in materials used in field equipment. During the period from 1930 until the beginning of the German campaign against Russia, when normal thallium sulphate* imports were completely cut off, our entire field-control program had been geared to poisoning with this material. Domestic stocks on hand furnished us with supplies for about two years. In the meantime our search for another poison to be used in place of thallium sulphate resulted in the substitution of zinc phosphide. The experiments conducted during this period are included in this report.

Species of Rats

We have four easily recognized species of rats in Hawaii; all of these rats will eat sugar cane when it suits their fancy.

The smallest and least frequently seen species is the Polynesian rat, *Rattus hawaiiensis* Stone (Fig. 1), which has been previously reported as rare, but is now abundant in certain areas of the Hana district on Maui and is also found elsewhere in the Islands. This rat when fully mature seldom averages more than 60 grams in weight, and is rarely seen by the average person as it lives in grass and brush areas

Fig. 1. The Hawaiian or Polynesian rat, *Rattus hawaiiensis*. Photo by courtesy of the Bernice P. Bishop Museum (84). The inside diameter of the jar is two inches.

*This term is the commercial designation. The chemical referred to is actually thallous sulphate, Tl_2SO_4.

away from human habitation. It is said to live on grass and weed seeds along with some vegetative parts of plants; it is very destructive to cane in spite of its small size. The Polynesian rat is the only species that has been observed actually feeding on sugar cane stalks during daylight hours, and is the most docile of the rats in Hawaii. In one instance a field worker pulled a live full-grown specimen of *R. hawaiiensis* out of his pocket to show the kind of rat that was eating the cane at that time. It burrows in stream or reservoir banks, on slopes or level grassy areas.

Stone (84, p. 10) gives a technical description as follows: "above, cinnamon brown or russet shading into cinnamon buff on the sides and light buff or buffy white below, strongly mixed with black hairs on the back and sides. Feet nearly white above, the dusky color of the legs overspreading the tarsus and carpus and narrowing to a point. Whole underside of the hind feet dark."

The three most common rats are the cosmopolitan species more familiar to every-one. The largest of these is the Norway rat, *Rattus norvegicus* (Erxlelen) (Fig. 2), sometimes called the gray, brown, wharf, or sewer rat, which is the most aggressive and pugnacious of all. It is characterized by its large size, blunt nose, moderately small and slightly haired ears, and a blunt thick tail so much shorter than the head and body that when it is bent forward it does not reach the nose. Full-grown specimens may weigh from three-fourths to one pound. The largest specimen of Norway rat handled in cage tests by the writer weighed 412 grams. The Norway rat prefers to live in or near camps or villages, especially near pig pens or poultry yards. It is not a tree climber but lives in or near the ground. The color of the body varies from reddish brown to brownish gray and is not a reliable criterion to distinguish between species.

Fig. 2. The Norway rat, *Rattus norvegicus*. The rat in the upper photograph has a prominent white patch extending from the belly up both flanks. This undoubtedly is a natural sport, as these wild rats were trapped at the pig farms in Kalihi Valley, Oahu.

The black, house, or roof rat, *Rattus rattus rattus* (Linn.) (Fig. 3), is smaller and more slender than the Norway rat, seldom weighing over one-half pound (227 grams). The nose is sharply slender, the ears are noticeably large and thin membraned without hairs, while the tail is slender and longer than the body and head. The color of this rat is blue-black above and slaty below.

The Alexandrine rat, *Rattus rattus alexandrinus* (Geoffroy) (Fig. 4), also called the yellow-, gray-, or white-bellied tree or roof rat, is classified as a subspecies of the black rat. It has all of the characteristics of the black rat except color which is grayish brown above, white or yellowish white below, more like the Norway. Both this species and the black rat can climb readily and may nest in trees or attics.

Schwarz (73, p. 6) of the National Museum, Washington, D. C., has differentiated between the grey-bellied rat, *Rattus rattus alexandrinus,* and the white- or lemon-yellow-bellied form which he designated separately as *Rattus rattus frugivorus* Rafinesque. He further comments that the white-bellied frugivorus, " . . . is primarily an outdoor rat that lives not close to man. . . . " In Hawaii we have not differentiated between these two forms.

Wherever large numbers of rats of any species are allowed to live undisturbed near cane, serious damage can result. The relative economic importance of these four species depends entirely upon the geographic location of the cane area under consideration. As an example, *R. hawaiiensis* is likely to be the predominate species in the upper fields bordering on or near brush and forest wastelands. On the other hand lowland fields in the same districts bordering waste areas on the coral flats near the ocean will be damaged principally by the black *R. r. rattus* or the *R. r. alexandrinus.* As an indication of the species found in one section of the islands (Kona district of Hawaii), Spencer's report (36, p. 12) showed that the proportion of the different species of rats caught in traps was 58 per cent black,

Fig. 3. The black rat, *Rattus rattus rattus.*

20 per cent each of the tree (Alexandrine) and Polynesian rat with only two per cent Norway. On the island of Kauai, the most destructive rat has always been the Norway.

FOOD HABITS

Rats, will on occasion, eat almost anything. The list of foods accepted by rats covers all known foods of man or animal. Rats apparently have a remarkable power of discrimination and by it they evidently obtain a good balanced diet in whatever situation they maintain themselves. The food of our field rat, however, is limited to what grows in the areas in which the rat happens to be living. Thus in the coffee district of Kona where the black rat predominates, coffee berries and twigs form a very appreciable part of the diet during the winter season (December to February). The fruits of the screw pine or pandanus[1], which grows in dense thickets along the
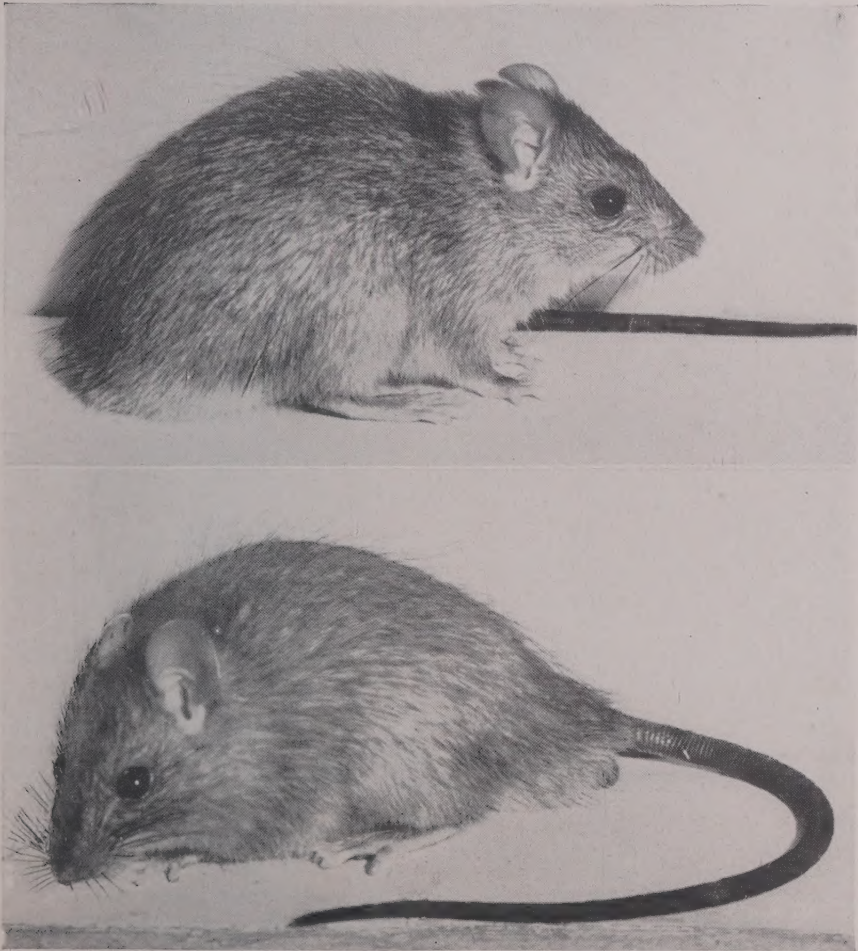
Fig. 4. The gray rat, *Rattus rattus alexandrinus.*

[1]*Pandanus odoratissimus* Linn.

seacoast and also in the gulches at low elevations, are eaten in great quantities throughout the year. During the late summer the beans of the algaroba[2] are a favorite food of the black-rat group living in the lowlands near the sea. Coconuts[3] are attacked in all stages of development. An especially provoking damage is the chewing of a hole in very young coconuts, before the meat has developed, which causes large numbers of them to fall to the ground prematurely.

In all parts of the Islands guava[4] seeds are eaten in great quantities during a long guava season (Fig. 5). This is true also for almost every other fruit and seed, such as the following:

Papaya[5], banana[6], coconut, grass and grass seed (notably the foxtails)[7], kukui[8], thimble berries[9], lantana berries[10], poha[11], popolo[12], and wild cucumber or balsam

Fig. 5. A guava fruit partially eaten by rats, showing a typical, circular pattern of seed hulls distributed on the ground. Photo by L. W. Walker.

[2]*Prosopis chilensis* (Molina) Stuntz.
[3]*Cocos nucifera* Linn.
[4]*Psidium guajava* Linn.
[5]*Carica papaya* Linn.
[6]*Musa sapientum* Linn.
[7]*Setaria lutescens* (Wiegel) Hubb.

Setaria geniculata (Lam.) Beauv.
[8]*Aleurites moluccana* (Linn.) Willd.
[9]*Rubus rosaefolius* Smith
[10]*Lantana camara* Linn.
[11]*Physalis peruviana* Linn.
[12]*Solanum nigrum* Linn.

apple[18]. If rats can gain access to a garden, they will add to their diet many vege-
tables, especially sweet potato, taro[14], pumpkin, as well as avocado[15], and maca-
damia[16] nuts.

Unusual parts of plants are sometimes eaten (Fig. 6). Thus, rats have caused
serious damage to pineapples on Lanai by eating the young flower buds as they
emerged from the base leaves of the plants. Rats have also chewed the young tender
tissue (meristematic) at the base of the short leaves in the crown of young pine-
apple fruits. At Manoa (Oahu), ti[17] petioles have been chewed by rats so that the
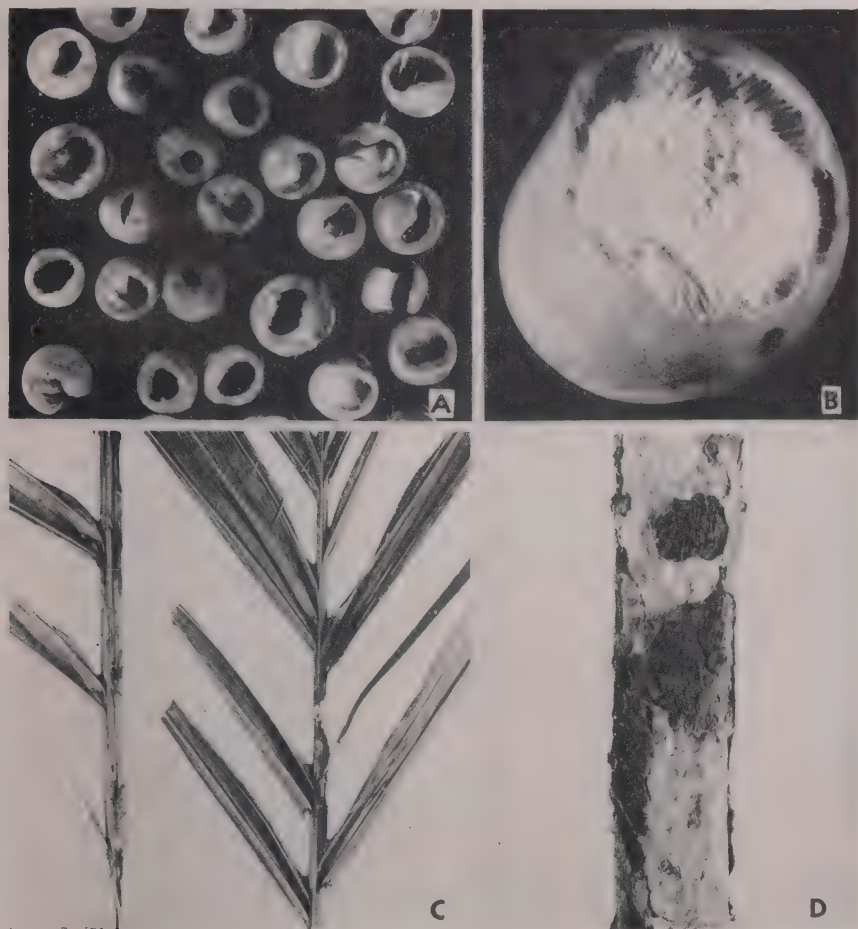
Fig. 6. Examples of rat damage to miscellaneous crops: *A*—chewed shells of macadamia
nuts; *B*—mango fruit partially eaten by rats (note that teeth marks are plainly visible);
C—frond of palm (*Pinanga* sp.) severed from plant by rats; and *D*—a stem of wild ti girdled
by rats.

[13]*Momordica balsamina* Linn.
[14]*Colocasia antiquorum esculenta* Schott
[15]*Persea americana* Mill.

[16]*Macadamia ternifolia* F.v.M.
[17]*Cordyline terminalis* Kunth.

leaves fall down and hang to the plant by mere shreds. In other instances the stems have been completely girdled. Rats sometimes gnaw out the eyes of sugar cane and scrape the root bands clean (smooth) before eating the internodes from the stalks.

When sugar cane is available, rats will secure most of their carbohydrate requirement from this source. But sugar cane alone is an unbalanced diet as has been amply demonstrated by Caum (9, p. 213) in his experiment with caged white rats. In this experiment one lot of rats was fed exclusively on sugar cane for 53 days. At the end of this test period Caum described the rats which were maintained on the sugar cane diet as, " . . . small, sluggish, unsteady on their feet, and scarcely able to open their eyes wide." These rats had remained infertile and showed all the symptoms of partial starvation, while rats fed on a normal diet grew to almost three times the average weight of the cane-fed rats and also produced normal young.

It appears quite definite that the availability of protein foods is the limiting factor controlling the increase of rats in cane and adjacent waste areas. Rats eat mice and insects of many kinds to secure the protein foods which are normally scarce inside cane fields and in brush-covered areas.

This craving for protein has not been overlooked in seeking suitable bait carriers for rat poisons to insure success in our poison campaigns. However, it has not been necessary to use highly concentrated protein sources, such as meat or fish, which have been found necessary in some of the cereal-producing districts of the mainland.

A study of the summary tables, compiled by Spencer (36, p. 13), of the more important foods found in the stomachs of rats examined during January to June inclusive (1937) from Kona, Hawaii, showed a large variety of foods representing every kind of natural food available, but the significant thing throughout the entire period was that almost half of the food had been grass.

Stomach dissection records of rats caught in a gulch on Kauai, compiled by Jordan (36, p. 1) showed that cane made up more than 50 per cent of the stomach contents. It was also noted that all of the rats caught showed a heavy consumption (16–20 per cent) of the coconut which had been used as the trap bait.

Nesting Habits

Rats retreat to good ground-surface cover before stopping to build a burrow. The favorite shelters for nest building are rock piles or rocky slopes heavily covered with weeds, grasses, or shrubs.

On the eastern end of Maui there are many Polynesian rats living in the rock piles, under the edges of large rocks or in the cracks between the rough lava rocks in the wasteland. These waste areas are generally overrun with climbing vines and shrubs—mostly guava.

The burrows of the Norway rat are much larger than those made by the Polynesian rat. These are to be found in thickly covered grassy drains or on the gulch slopes next to cane lands as well as inside the cane fields. Most burrows are not deep, certainly not below two feet, but they may be several feet in total length, and very often will follow along the lines of hilled-up cane.

It is almost impossible to locate rat burrows in a mature cane field before the cane is burned and cut, but after harvest many burrows will be visible in the open ground around or under cane stools or small rocks. Inhabited burrows usually have some fresh soil piled in front of the main opening. There are always other open-

ings which may be used as emergency exits, which have no loose soil scattered about, and these may be completely concealed. In addition, these burrows often contain one or two blind channels which are pointed toward the ground surface to serve as special escape exits.

A favorite place for a Norway rat's nest is directly under a stool of cane or a rock. Thus in a loose friable soil in an irrigated field, the rat can take full advantage of the overhead support offered by the cane roots or the rock to prevent the destruction of its nest. The nest is generally placed so that it cannot be submerged by irrigation or excessive rain. It is usually roughly spherical, six or seven inches in diameter, and well lined with fine portions of dry cane leaves and grass.

The black rat and the closely related tree rat (Alexandrine) live above ground in trees, shrubs, or among rough lava rocks. Pemberton (62, p. 7) has called attention to the pandanus thickets as being their favorite nesting places (Fig. 7). The nests are composed of a tight ball of dry pandanus leaves located in the center of the cluster of leaves found at the ends of the limbs. Black and Alexandrine rat nests are also common in the tops of coconut palms and in algaroba trees (Fig. 8).

Reproduction

If rats can find good shelter and get plenty of food, they are very prolific. Sex maturity is reached in from three to four months. The period of gestation is 21 days,* with from four to eight young per litter, and 12 is not an unusual number

Fig. 7. The cluster of leaves at the end of a limb of the pandanus tree is often the favorite nesting place of the black rat or the Alexandrine rat. After Pemberton (62).

*Silver (76, p. 4) states that, "Accurate data on the white rat, which is an albino form of the common house rat, show that the period varies from 21 days and 15 hours to 22 days and 16 hours." Other authors claim that this normal period may be prolonged when a pregnant female is nursing an earlier litter.

for a well-fed older Norway. Full-grown females when about 1½ years old are said to have larger litters than young individuals.

Trapping work on the island of Hawaii, which was conducted by the Territorial Board of Health between September 1, 1922, and February 23, 1923, and reported by Pemberton (62, pp. 2–3), showed females to be in the majority in each species of rats caught and, " . . . especially so in the case of the black rat . . . " where 63 per cent were females.

Spencer (36, p. 12) made extensive studies of rats caught in the Kona district of the island of Hawaii from May 1936 to June 30, 1937. His report showed that out of a total of 35,073 rats caught, 16,842 or 48 per cent were females. Of this number of females, 1,513 or 9 per cent were pregnant, with an average of 4.7 embryo per female. His table showing the distribution of pregnancy by months indicated that the six-month period from October to March inclusive was one of low pregnancy averaging only four per cent and with less than two per cent for the lowest month (December). The period of April to September inclusive was a period of high pregnancy, averaging over 11½ per cent, and with June and September as the high points ranging up to 15 per cent.

Jordan (36, p. 1) reporting on rat trapping in a gulch at Puhi, Kauai, during May 1937, showed that 78 per cent of the rats caught were Norways and that 58 per cent of these were females. Twenty-nine per cent of the Norway females were either pregnant or caring for families.

Fig. 8. A typical rat nest in an algaroba grove at Kahala, Oahu. This nest was occupied by the Alexandrine or tree rat. Rat nests are distinguishable from bird nests by being larger and made almost entirely from coarse twigs and leaves available in the tree. A dove's nest may furnish the foundation for a rat's nest.

Natural Enemies

The mongoose, *Herpestes javanicus auropunctatus*,* Hodgson, is the only important natural enemy of the rat in Hawaii (Fig. 9). This animal, a native of India, was imported from Jamaica, British West Indies in 1883 and liberated on the islands of Hawaii, Maui, and Oahu to fight rats in cane fields. It was not introduced into Kauai.

Since that time much has been said and written for and against this animal. In addition to killing rats and mice, the mongoose, unfortunately, preys on domestic fowl, wild game and their eggs. This lack of discrimination and an inclination to catch whatever is easily available have given poultry raisers and bird lovers much cause for complaint. From the viewpoint of sugar cane agriculturists, however, the mongoose does much more good than harm, because he rids cane areas of many rats and insects. Schwarz (73, p. 6) recently stated that, " . . . in the West Indies . . . the introduction of the mongoose has effectively controlled the Norway, Black and the Grey-bellied rats, but not the White-bellied† rat, which naturally has a tendency to nest in trees."

During a study of secondary poisoning, discussed later in this paper, the writer kept two wild mongooses in cages for some time and fed them live rats. While these wild mongooses were shy, they were savage and would "spit" vigorously whenever an observer drew close to the cage, and were always over-anxious to get at the rat as it was being transferred to their cage. Each time a rat was being transferred to one of the mongoose's cages, that mongoose would reach through the cage door and seize the rat before it could be even hurriedly thrust through the opening. The most agile rat seemed to have no chance to even put up a fight with the mongoose (Fig. 10). In a flash and unerringly, the mongoose always grabbed the rat by the back of the neck on the first pass and, while growling like a cat with a mouthful of mouse and with his long sharp teeth pierced through the neck, would begin to crush the rat's bones. The cracking of the bones during this fiasco fight was plainly audible to the observer. The initial struggling of the rat generally ceased in less than 30 seconds. When the rat became limp, the mongoose would put it down and then take a few more savage bites around the rat's head to make a finished job of the killing. In a few minutes the mongoose would start eating the rat, beginning at the head. He would leisurely yet completely consume the rat including the viscera leaving, as the only evidence of a hearty meal, a part of the tail and perhaps a foot or two and a small strip of skin with hair.

Since no introduction of the mongoose has ever been made on the island of

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*The Hawaiian mongoose has been erronously called *Mungos* (*Herpestes*) *birmanicus* or *H. edwardsii* which are distinctly larger animals than the one actually in Hawaii. R. I. Pocock, F. R. S. of the British Museum of Natural History (64, p. 242) following his description of *Herpestes javanicus auropunctatus*, calls attention to the fact that, "It was this small Mongoose, not *H. edwardsii* as formerly supposed, that was introduced into the West Indies, and is now found in most of the islands, the British Museum having specimens from Jamaica, St. Lucia, Barbados and elsewhere. This was pointed out by G. M. Allen [*Bull. Mus. Comp. Zool.*, Vol. 54, p. 217 (1911)] who identified his specimens as *Herpestes birmanicus* and told the story of the shipment of the original consignment from Calcutta to Jamaica." Our Hawaiian mongoose, therefore is *H. javanicus auropunctatus*.

†*Rattus rattus frugivorus* Rafinesque. See description under heading "Species of rats."

Fig. 9.   The only effective natural enemy of the rat in Hawaii is the mongoose.   Photo by L. W. Walker.

Kauai, it may be more than mere coincidence that the Norway rat has always been the dominant rat on that island. Barnum (6, p. 423) blamed the uniformly higher rat damage in 1927 and 1928 on Kauai on the absence of the mongoose, and it is now generally conceded that rat troubles on the Kauai plantations were consistently more acute and widespread than on the other islands until the more systematic control method, namely, that of prebaiting in cane lands, was developed in 1938.

After his examination of 356 pellets of mongoose excrement collected in cane fields at Honokaa, Pemberton (62, p. 42) reported that, ". . . 52.2 per cent . . . contained nothing but rodent parts, . . . 36.2 per cent containing a mixture of insect and rodent parts . . . [and the remainder] 11.5 per cent . . . contained nothing but parts of insects."

According to Pemberton (63, p. 12) other foods eaten by the mongoose in captivity are ripe bananas, small amounts of fresh coconut meat when removed from the shell, bread, eggs (no shells), birds, fish, live crabs, lizards, centipedes, cockroaches, frogs, toads, earthworms, all insects, and all kinds of meat. When confined together mongooses will kill and eat the weaker members of the group.

Fig. 10. In a flash the mongoose savagely grabs the rat by the back of the neck, and makes quick work of the killing by biting completely through and crushing the bones. Photo by L. W. Walker.

In 1935 a report came from fieldmen that the mongoose was eating the poisoned cereal rat baits placed in the cane. No reference was found in the literature which mentioned dry cereal as food of the mongoose. Accordingly, to determine this point dry cereal was made the subject of a cage test. A wild mongoose was confined in a cage for a period of over six weeks and fed sugar cane, whole wheat, flaked wheat, rolled barley, and rolled oats. Some meat scraps were given every four or five days and water was provided at all times. During the entire period the mongoose refused to eat any of the cereals listed, even though at times it was almost starved. Therefore it is quite probable that cereal rat bait is not eaten by the mongoose. Occasionally, however, a mongoose will upset or scratch out some of the rolled oats from a feeding station, but this act may be the result of an interest in the oil, the pursuit of a rat, or mere curiosity.

Dogs have been used on several plantations on Kauai at various times in past years to catch rats in the harvest field, but since baiting and poisoning in feeding stations have reduced so materially the rat population in the fields, this method has been abandoned. However, it is possible to make a substantial contribution to plantation rat control by organizing this branch of the work. A crew of three or four dogs in charge of one man or boy can cover the harvest field and systematically dig out all of the burrows and catch many rats in a day. Formerly a group of four dogs often caught 400 to 500 rats per day and catches of over 600 have been reported. To operate successfully, one crew of dogs should work only three or four hours a day and should be trained to stay near by and obey their master instead of roaming the field unattended. In this way the field can be searched systematically. The rat terrier is the breed of dog most highly recommended. This dog has a reputation as an able and aggressive rat catcher. Adequate arrangements by the plantations for the feeding, housing and supplying medical care for these dogs should overcome some of the health objections that have been voiced against this plan in the past.

Cats have been observed in the cane fields far from human habitation, thus indicating that they can live by hunting only. However, they have never been any great factor in rat control. Actually, cats in sufficient numbers have never been available, so it has not been possible or practical to keep them in any desired area. However, in chronically bad areas it might be of value to gather up stray cats and liberate them in these critical spots. Such an endeavor has possibilities of success now, if zinc phosphide only is used as the poison agent in the area.* Cats about a camp or village certainly will aid in keeping down the population of rats and mice, so their presence around the homes should be encouraged.

The native owl, *Asio occipitrinus sandvicensis* (Blox.) mentioned by Pemberton (62, p. 43) has been observed at work on Maui, but it is not sufficiently numerous to be of economic importance.

RAT POPULATION

Distribution in Wet and Dry Areas:

The most obvious factors affecting a rat population are the natural cover and food supply, modified by any natural enemies that may operate. The abundance of natural food for rats in districts of ample or plentiful rainfall is well known. This,

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*No secondary poisoning can result from the use of zinc phosphide. See data and discussion under the subject of "Secondary Poisoning."

combined with great expanses of good undisturbed cover for nesting, provides ideal conditions necessary to promote the establishment and maintenance of a large resident rat population. When comparatively small areas of cane are surrounded by such conditions, the problem of rat control becomes a major economic endeavor.

The number of rats is greater in cane areas having a high percentage of cane actually bordering an undisturbed wasteland than in large compact fields having a comparatively low per cent of cane directly bordering on such areas. Those plantations having broken wasteland and stone-pile areas within the cane fields find it more difficult to obtain good control, due to this excellent harborage, than do plantations where the ratio of field borders touching wasteland to acres of cane is lower. Then, too, plantations in wet areas are constantly covered by much more grass and weeds within the cane fields than those in the dry districts. These plants supply additional cover for rats early in the life of the cane crop and inevitably develop seeds which furnish protein food.

Figs. 11 and 12. Heavily wooded or brush-covered plots frequently interspersed in cane areas make adequate control of rats difficult (Field 25, Kaeleku Sugar Company).

The sugar lands at Hana, Maui, furnish an especially favorable environment for the development of a high rat population (Figs. 11 and 12). This is due to the vast areas of forest waste in this region of ample rainfall, compared with the relatively small total area of land actually in cane. The cane area is broken into many very small fields, some of which are entirely encircled with rocky forest waste. In addition there are many stone piles and small sections of forest within the fields themselves. These forest areas serve as vast preserves for the development of rat populations which can overflow and pour into the cane areas and cause tremendous losses. These losses may begin almost as soon as the cane has formed millable stalk.

On the other hand the irrigated plantations have relatively few rats on the leeward side of the islands of Maui, Oahu, and Kauai, where the rainfall is limited, and the fields are relatively free from weeds and have a minimum of gulches and wasteland. Under these dry conditions rats accumulate only in areas where food

Figs. 13 and 14. Typical scenes of newly harvested cane fields (Fields 8 and 14 at Kaeleku Sugar Company). The small gulches and drains, which traverse these cane fields, are covered with thick brush and form an ideal habitat for rats. Rats taking refuge in these areas, immediately following the harvesting of the cane, are easily poisoned.

and water are available, such as in algaroba groves, camps, pig pens, or around and near dependable sources of water, like a continuously used irrigation ditch or reservoir. On one irrigated plantation certain fields always have a rat infestation requiring repressive measures because these areas are immediately adjacent to large permanent colonies of rats living in a brush-covered gulch. Other fields, far removed from any permanent wasteland, require no rat-control measures during an entire crop. Pemberton (62, p. 14) pointed out that, "The less gulches, rock piles, permanent waste areas and grass, weeds, shrubs, cover crops, etc., the smaller the rodent population should be."

Migration Into Cane Fields:

Whenever a field of cane is harvested, rats that were living in this mature cane move to a safer cover (Figs. 13 and 14). Where fields are burned at harvest, this escape movement is hastened, although some may stay in their burrows for a few days. Garlough (36, p. 9) has observed, " . . . that the Norway rats may remain in their nests in the canefields four or five days after the cane is harvested; but the Hawaiiensis which burrows in the fields leaves immediately after it is cut." However, rats may continue to live in the larger stone piles even when they are isolated in the center of a field (Figs. 15, 16 and 17).

Some areas on Kauai offer typical examples of good rat terrain. There the rats escape from cane fields being harvested into neighboring wooded or brush-covered gulches, stone piles or stone fences, panicum-grass-covered drains, or other nearby fields of mature cane. By the time the next cane crop has grown for eight or ten months and has made a good cover and some millable cane, the rat population in the adjacent waste areas has become large and perhaps overcrowded. The rats will then re-enter the cane field, at first gradually and then at a progressively increasing rate by well-defined routes, the exact places being determined by the thickness of the adjacent cover. Definite trails or runs through undisturbed grassy lands adjacent to cane have been noted occasionally on both Kauai and Maui. Feeding stations placed on these trails tend to bring prompter consumption of bait than stations off the beaten tracks. In one instance several rat trails leading from grassy wasteland converged to a plank across a continuously flowing irrigation ditch. This plank was used by the rats to gain access to sugar cane on the opposite bank. In another case rats from the waste slope across a valley stream used overhanging limbs and driftwood as bridges to cross the stream.

The first serious damage to new cane fields will occur along the edges. Cane bordering on the upper end, or head of gulches extending into the cane fields, are favorite points of early, continuous, and severe attack. Later, rats will enter the cane fields along the steeper sides also. This damage is easily detected by even casual inspection because the cane falls down and flattens out in typical fan shapes from these points of entrance.

As the cane becomes a tangled mass after 12 months of age, rats in increasing numbers actually move into the field permanently, digging holes and building their nests under rocks, in crevices or under cane stools. If prompt and effective control measures are not put into effect, the damage can extend to involve the whole field in a short time.

Instances of severe invasions of rats from forest wastelands, during December

Figs. 15 and 16.   Parts of Field 30, Honokaa Sugar Company, just harvested, showing rock piles which offer permanent cover so necessary for rats, until the new crop of cane has grown. After Pemberton (62).

and January, have been observed at Kaeleku Sugar Company. Fieldmen have reported that rats have moved into a field as far as 40 to 50 feet in one night, leaving the cane flattened out on the ground, with perhaps only ten per cent of the stalks, mostly upright young suckers, left standing. The causes contributing to these winter invasions of rats are not entirely clear. A gradual rise in damage in rat-infested areas can be expected in October with the peak of the curve extending from December to February of each year.* The normal increase in rat population in the forest waste areas, following the summer litters, must account for much of the migration into the cane fields. The seasonal fluctuation in the supply of natural wild foods, such as the guava, may contribute somewhat in accelerating this rat movement. During some seasons, between October and December, there may be a further drastic reduction in these supplies of natural foods due to periods of protracted drought. These factors when working together may cause extra large hordes of rats to migrate into the cane, resulting in an acute rat invasion.† Many fieldmen feel that

Fig. 17. Field 30, Honokaa Sugar Company, just after harvest, showing excellent rat cover within the cane field. After Pemberton (62).

*For more detail see heading "Seasonal Fluctuations in Rat Populations" (Table VIII and Fig. 35).

†Lantz (44, p. 25) relates numerous instances of migration and invasions of which the following abstracts are typical:

"In England a general movement of rats inland from the coast occurs every October. This is known to be closely connected with the closing of the herring season. During the fishing the rodents swarm to the coast, attracted by the offal left in cleaning the herring; and when this food fails, the animals troop back to the farms and villages.

"In South America plagues of rats are often periodical, occurring in Parana, Brazil, at intervals of about thirty years and in Chile at intervals of from fifteen to twenty-five years. It has been discovered that these plagues in the cultivated lands follow the ripening and decay of the dominant species of bamboo in each country. The ripening of the seed furnishes for two or more years a favorite food for rats in the forests, where the animals multiply greatly. When this food fails, they are forced to the cultivated lands for subsistence. In 1878 almost the whole crops of corn, rice, and mandioca in the State of Parana were destroyed by rats, causing a serious famine. (*Nature*, Vol. 20, p. 65. 1879.)"

heavy cane damage from rats always occurs during or immediately following a period of cooler weather, suggesting the theory that the rats need the extra carbohydrate at that time to keep them warm.

Some other disturbing factors, causing a shift in rat populations in or from their natural habitat, are directly traceable to operations by man. For example, the clearing of wasteland in preparation for planting to sugar cane is quite likely to result in rat damage to any adjoining cane fields. Even the cutting of trails on a brush-covered hillside, preparatory to planting rows of young forest tree seedlings, was a sufficient disturbance to the natural cover in another instance to result in a wave of damage in the adjacent cane fields. The cleaning of reservoirs and ditches following the harvest season may scatter any resident rat population into adjacent cane and result in increased damage unless counter measures are made effective.

Abundance:

The actual rat population which is responsible for a given amount of damaged cane at harvest time in a specific field has always been a matter of conjecture. It is very difficult to make a close estimate of the exact extent of a rat population in a field, or even any part of it. Pemberton (62, p. 18) has reported estimates of a rat population based on the number of rats caught by trapping over short periods of time at Honokaa Sugar Company. In a 105-acre field, 1,000 traps were placed and tended daily for three months (April, May and June 1923) while harvesting was in progress. Exclusive of rats dying from the heavy applications of poison made at intervals during the year, the total rats caught for the three-month period amounted to 37 rats per acre. At the close of this period the daily catch had dropped to a low figure of 12 rats per 1,000 traps (1.2 per 100).

The seven-year average of rats caught per trap per month at Grove Farm Company was reported by Barnum (6, p. 424) to be 7.11* which is equivalent to 23.7 rats per 100 traps per day. This high rat population index, with its resultant serious rat damage to cane, was general on the windward side of Kauai at the time when thallium-treated torpedoes first came into wide use. Beginning with the spring months of 1929 the rat populations were greatly reduced on Kauai by this new poison. However, rat-trapping indexes of 12 to 30 rats per 100 traps were common up to the time (1939) when systematic prebaiting became a general practice.

A specific example of the number of rats caught per 100 traps, in relation to cane damage and total rat population, is found in the records from Field 4,† Kilauea Sugar Plantation Company for the 1937 crop harvested during June and July. During this period the records show 28.9 rats were caught per 100 traps which amounted to 13.3 rats per acre over 70 acres of cane. In addition another 15 rats per acre were caught by dogs in the harvest field. These data indicate that many more than 30 rats per acre were actually in the field at harvest time. The plantation agriculturist recorded the cane damage in this specific instance as being greater than 25 per cent.

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*To convert rats per trap per month to rats per 100 traps per day, using figures in test, we have $\dfrac{7.11}{30} \times 100 = 23.7$.

†For further details see heading "Early Results at Kilauea Sugar Plantation Company."

In 1938 as a result of general torpedo poisoning, trapping and experimental pre-baiting, the rat population at our Kauai Variety Station had been reduced to around 8 rats per 100 traps per day, yet cane damage was severe in places adjacent to waste-land. However, under a systematic prebaiting program the number of rats per 100 traps has steadily declined until this figure now (1944) stands at a yearly average of 1.3 to 1.5 rats per 100 traps (Doty 23, pp. 76–77). Cane damage ceased some-where between 5 and 1.5 rats per 100 traps. Therefore, on the windward side of Kauai, in order to maintain this satisfactory condition, recent calculations* of the consumption of poisoned oats under the prebaiting system indicate that at least 20 to 35 rats must be killed per year for each acre of cane maintained under cultivation. In the study at the Kauai Variety Station it was clearly established that this rat population represented the amount of reinfestation that occurred from surrounding adjacent wasteland, and was not a part of a resident population in the cane (Doty 23, p. 80).

Instances of extremely high rat populations in cane areas immediately adjacent to wasteland are frequent at Hana, Maui. In a 10-acre tract, Field 4 at Kaeleku Sugar Company, at least 275 to 300 average-sized rats were killed in May 1941 from a single round of poison.† A study of recent records of poison consumption at Kaeleku Sugar Company indicates that 120 to 140 average-sized rats are being killed annually for each acre of land in cane for the entire plantation.‡

CANE DAMAGE

The damage to cane by rats may be very great—so great in fact that what might have been a good crop may actually prove a total loss. Rat damage tends to increase from September and reach a peak in December or January of each season. This trend coincides with the increase in consumption of bait at feeding stations which in turn is due to the increase in population resulting from the maturing of summer litters.§

Rats seem to prefer soft, low-fibre canes of high sugar content. They are espe-cially fond of Badila and 31–1389, both of which are soft, sweet varieties. If these varieties are growing in fields bordering on, or surrounded by larger forest waste areas, heavy damage can be expected unless the control measures taken are very effective. At Kaeleku small fields of 31–1389 cane, which were more or less sur-rounded by waste forest land, were inspected in 1943. This cane was 12 to 16 months old and had been estimated to yield from 60 to 70 tons per acre, but 90 per cent of the stalks were so severely damaged by rats that they were flattened to the ground. Even as very young cane 31–1389 is so attractive to rats that it is some-times attacked before the stalks have produced as much as a foot of millable cane. When it is attacked by rats, it is more adversely affected than most other varieties because being so soft it breaks off more readily than do such varieties as Yellow Caledonia, POJ 2878, 32–8560 or 32–1063. While older cane which has been dam-

*See heading "Consumption Records" for tables of consumption per acre and estimated number of rats killed (Table V, Fig. 34). These calculations were made from detailed data supplied by The Lihue Plantation Company, Ltd.

†See heading "The Control Problem at Hana."

‡See Table V and Fig. 34.

§See Fig. 35 for details.

aged by rats may continue to grow slowly if only a small shred of rind remains to connect the stick with the stool, young cane is flattened out and soon dies. Honohono, *Commelina nudiflora* Linn., morning glory, *Ipomoea* sp., and other weeds spring up in the open spaces where the young cane has fallen down and smother any suckers which may start. All of this may cause a much greater total loss than the original rat damage. At harvest the weeds may have attained a greater tonnage than the cane and they cannot be economically separated.

Plantation men feel that 32–8560 and POJ 2878 may be ranked second to 31–1389 in order of their susceptibility to serious rat damage. If there are only a few rats present in a well-grown field of 32–8560, they choose first the thin, spindly and weak sticks that are about to die from shading. Yellow Caledonia may be badly attacked if softer varieties are not near at hand. Rats are especially destructive to soft canes in seedling-trial plots. Here they will concentrate on and wreck certain canes while others will be ignored entirely. However, hardness of rind is no guarantee of immunity against rat damage. At Kahuku Plantation in 1939, one of the hardest canes (33–7673) in a seedling area was badly damaged while many softer canes were left untouched. Certainly no cane is immune when rats can cut through the hard shell and extract the kernel from a matured macadamia nut without too much difficulty (see Fig. 6).

In general, rats first attack cane by chewing out an internode at a point somewhere between the surface of the ground and 18 inches to two feet above. However, instances of heavy rat damage above a trash blanket, and two to four feet above the ground, were reported from Kauai in 1938. After the stalks have fallen over, a number of adjacent internodes along the flattened portion of the stick may then be eaten also. Figs. 18, 19 and 20 illustrate excellent examples of rat damage to cane. Even in daytime *R. hawaiiensis* have been observed as they feed on cane stalks that are lying in a horizontal position. Very often nearly all of the stalks of an entire stool will be cut so that they fall over and flatten out. Unless such injured cane is harvested within a short time, even the less severely damaged sticks soon ferment and lose sugar. This deterioration is brought about by various organisms which may gain entrance to the stalk through these large wounds. Martin (49, pp. 265–266) mentions that red rot disease is found frequently in several internodes both above and below the limits of actual rat injury. Such losses are of much greater importance than the small amount of cane actually eaten by rats. It is readily seen that one inch of cane eaten from a stalk results in the loss of the sugar contained in an entire stalk 6 to 20 feet in length. Therefore, cane fields injured by rats reflect their losses by yielding poorer juice.

The extent of the losses to Hawaiian cane fields from varying amounts of rat damage has been carefully studied and many data secured in the past. Pemberton (62, p. 19) reported on the work of G. H. Haldeen, chemist, showing that in 1920 at Honokaa Sugar Company, " . . . it took nearly twice as many tons of rat-injured cane to produce a ton of sugar as sound cane, owing to juice deterioration. This was prior to poison control at Honokaa, and from 25 per cent to 40 per cent of the canes were said to have been rat damaged." Further work by P. H. Bartels, Honokaa Sugar Company, showed that the plantation lost 19.17 per cent of the 1922 sugar crop from causes due to rat injury. This figure included losses both from the injured cane and from dead cane left in the field, the total estimated to be 25 per cent
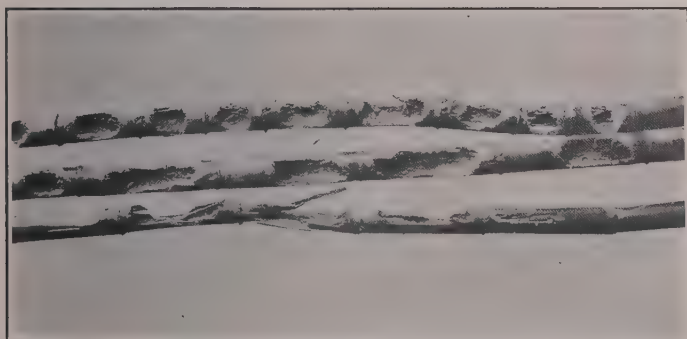
Figs. 18, 19 and 20. Rats can literally ruin sugar cane if adequate control measures are not executed. After Pemberton (62).

of all cane on the plantation. This figure may well represent a sugar loss so great as to amount to the difference between success and failure on many plantations. Pemberton (62, p. 19) also reported on studies by A. Fries, chemist of Honokaa Sugar Company, which amply confirm the above findings. Fries selected 18 separate lots of "rat-injured" and "sound" canes for analysis: "In each case entire sticks were cut and the total extracted juice was used for comparative tests. The selected rat-injured cane was not badly injured, there being only from one to three injured joints per stick. The sound canes were selected from the same stools as the injured ones, and an attempt was made to have each of the same age and height for each separate lot. . . . The average from the eighteen lots showed a requirement of 10.41 tons of cane for a ton of sugar in the rat-injured lots, and 8.77 tons of cane for a ton of sugar in the sound lots. This is an actual sugar loss of 14.9 per cent in canes only mildly rat damaged." These results show definitely that large losses in sugar may occur in only slightly rat-damaged cane.

"It was not until a serious effort was made to determine the sugar loss in injured canes, . . . that attention was greatly given to the extent of field damage," stated Pemberton (62, p. 23). He made extensive stalk counts during 1922, in 11 different fields. Out of a total of 24,100 stalks examined, an average of 18.9 per cent was damaged by rats. Elliott (26, pp. 140–144) reported on 26 separate tests in five fields, conducted at Paauhau Sugar Plantation Company (February to May 1924), covering the sugar loss due to rat-injured cane. He found a true average of 32.92 per cent of the stalks rat damaged in some degree. This amount of injury resulted in 5.86 per cent of loss in sugar per acre. When this loss is converted into dollars and cents, it appears more important. If we assume a yield of seven tons per acre, having a value of $50.00 a ton in the field, a 5 per cent loss due to rat damage amounts to .35 ton of sugar valued at $17.50. Surely this loss cannot be disregarded. These data did not include losses from dead stalks left in the field at harvest.

Dead cane left in a field at harvest time, since it cannot be weighed and does not appear on the books, is often ignored as an uncontrollable and inevitable loss. Moderate rat-damaged cane in wet areas along the Hilo and Hamakua coast of the island of Hawaii is accepted without much concern by plantation personnel because it may be mixed with cane which died from other causes. Extending the length of the cropping cycle increases greatly the final losses from rat-injured and dead cane. Pemberton (62, p. 23) reported on studies made at Honokaa Sugar Company during 1922 which give us examples of the extent of these dead-cane losses. Figs. 21 and 22 show typical parts of these fields after the good cane had been harvested. Fields having only 5 to 10 per cent of the sticks damaged have no appreciable dead cane left after harvesting. If the damage amounts to 15 or 20 per cent it becomes quite noticeable and where the damage amounts to 30 per cent, 40 per cent, or over, it is glaringly evident. By assuming a linear foot of an average cane stalk to weigh one-half pound, Pemberton (62, pp. 22–23) computed the amount of dead cane in Field 9, Pacific Sugar Mill (view shown in Fig. 21), to be 11.3 tons of dead cane per acre left on the ground. He made a similar examination in August 1922, in Field 28, Honokaa Sugar Company, in a location where the cane had been severely attacked by rats, and found the calculated figure to be 38 tons of dead cane per acre remaining in the field.

Fig. 21. View of Field 9, Pacific Sugar Mill, following harvest showing heavy losses in dead cane left in the field, due almost entirely to rat damage. After Pemberton (62).

Fig. 22. Field 19, Honokaa Sugar Company after harvest. Rat damage was responsible for most of the dead cane left in this field. When cane is mechanically harvested, all of this worthless material goes to the mill and contaminates the good juices. After Pemberton (62).

Previous to the 1939–1940 crops, rats exacted a heavy toll from the plantations on windward Kauai, amounting to as much as 25 to 30 per cent of their crops over whole fields, with 80 to 90 per cent of the cane cut down in limited areas at the head of gulches or next to rocky forest wasteland. However, due to the continuous and systematic program of baiting and poisoning in feeding stations during the last few crops, rat damage has been reduced to relative unimportance, being now confined to a few neglected spots.

Diseases Carried by Rats in Hawaii

While it is beyond the province of this paper to treat the subject of rat-borne diseases in any detail, yet attention should be called to the real health hazards brought to our homes by the presence of an abundant rat population in our cities, towns and villages.

The Rat and Mosquito Control Committee of the Chamber of Commerce of Honolulu (10) has recently (1943) published a popular treatise on rat control in which the dangers to health are emphasized.

Of rat-borne diseases in Hawaii, bubonic plague, infectious jaundice (Weil's disease), endemic typhus fever, and trichinosis are the most important, while rat-bite fever and amoebic and bacillary disentery are less dangerous.

Rats may also transmit certain animal diseases such as hog cholera, swine erysipelas, and fowl tuberculosis. They are reservoirs for 11 species of internal parasites which may infect man.

Bubonic plague is the most important rat-borne disease. This fatal disease occurs only in the Hamakua district of the island of Hawaii and in the Makawao district of the island of Maui. The causal organism is *Pasteurella pestis* (Lehmann and Neumann) Bergey, *et al*. It is transmitted to man by the bite of an infected flea. Rat fleas become infected with plague by feeding on a sick rat (4), (50) (29, pp. 35–52). When a rat dies of plague, the infected fleas must seek a new host (whether rat or human) which they promptly infect with the dread disease.

Infectious jaundice (Weil's disease) is caused by the organism *Leptospira icterohemorrhagiae*. The presence of this organism in rats in Hawaii was first reported by Alicata (1, pp. 95–101) in 1937. It is found in the blood and urine of all infected animals. It is a serious disease in man and is readily transmitted to him through abrasions of the skin or through the mucous membrane. Men working in cane fields known to harbor infected rats should have the protection of good footwear to prevent actual contact with polluted soil, as well as the use of disinfectants to treat any abrasions of the hands or feet. It may be conveyed by drinking polluted water or eating food contaminated with the urine of infected rats. This disease is found in areas of heavy rainfall. For interesting details the reader is referred to Stitt's book on tropical diseases (83, pp. 359–361).

Endemic typhus fever, caused by the virus *Rickettsia prowazeki* var. *mooseri,* like the bubonic plague is transmitted by the flea from rat to man. Alicata (2, pp. 57–60) has recently demonstrated that, in addition to the rat fleas, *Xenopsylla cheopis* and *Ceratophyllus fasciatus,* the very prevalent sticktight or chicken flea, *Echidnophaga gallinacea,* can carry and transmit endemic typhus fever. Rats have been caught in Honolulu with each carrying several hundred chicken fleas. This fact alone amply accounts for the prevalence of typhus fever in Honolulu.

Trichinosis is primarily an animal disease, being prevalent among rats and pigs. It is caused by a small parasitic nematode, which becomes encysted in the muscles of its host. Pigs acquire the infection by eating infected rats or infected raw garbage. The infection is passed on to man by his eating under-cooked pork which contained the cysts.

Control by Gassing

Rat-control measures which could be applied on a large scale in cane fields are gassing, the use of virus, destruction of natural cover, trapping, and poisoning. However, gassing is seldom used and there is no suitable virus available in the Territory. Hence, our chief means of control are the destruction of natural cover, trapping, and poisoning.

The use of gas to control rats in the cane field has been tried experimentally from time to time, but its commercial use has been very limited. The most effective fumigant for gassing rats is, undoubtedly, the dust of calcium cyanide.* In Hawaii, however, the gassing of burrows in the harvest field has proved to be wasteful of labor as well as dangerous to the operator, and is inefficient because our generally porous or rocky soil allows the gas to escape too easily. At Kaeleku Sugar Company efforts to gas rats in stone piles failed to drive them out because the gas arose too rapidly to be effective in penetrating laterally close to the ground where the rats normally live.

Attempts to gas burrows in a newly harvested field resulted in the escape of gas from crevices in the ground around cane stools or between rocks, covering an area of five or six feet, with very little success in killing rats. However, the Territorial Board of Health has found this method very useful around buildings, especially in the plague area, and under some conditions where poisoning is not deemed desirable.

Chlorine gas, confined in a small cylinder controlled by a hand valve with a long rubber hose attached, has been used experimentally on Kauai to gas burrows in a harvest field in the same manner as calcium cyanide. It has the advantage of being heavier, so that it settles into the holes and stone piles somewhat better than calcium cyanide dust. It is also very dangerous so must be handled only by competent trained personnel. Its practical usefulness in cane fields is debatable.

Control by Use of Virus

The illusion still persists that rats can be inoculated or infected with diseases, which will cause serious epidemics in rat populations. Actually rats have continued to persist in large numbers in spite of such introduced infectious diseases or in spite of many naturally occurring rat diseases, including the dreaded rat plague caused by *Pasteurella pestis*. The best known of these introduced diseases, the so-called rat viruses caused by several strains of the bacterium *Salmonella enteritidis* Gaertner, has proved to be very ineffective except when used on rat populations of very high density, or when used in such high concentrations and so frequently as to be impractical. Nevertheless some of the strains of this disease have been isolated and are still being employed for anti-rodent control in mainland United States and in Great Britain. The more important of these strains have been given the following

*The effectiveness of calcium cyanide is dependent on the absorption of moisture from the soil to cause the liberation of the poisonous hydrocyanic acid gas.

names: Loeffler, Danysz, Mereshkowsky, Ratin,* Liverpool, London, Ready Rat Relief, and Institut Pasteur.

Pemberton secured from the Agricultural Experiment Station at Sugame, Tokyo, Japan, December 8, 1922, fresh cultures of the Loeffler, Danysz and Mereshkowsky strains for trials at Honokaa Sugar Company (62, pp. 25–26). Rodents were fed these cultures mixed with rolled oats; at the same time other commercial virus preparations were received from the mainland and tested—all were without noticeable effect. This work was accepted as conclusive as to the effectiveness of such cultures and no further tests of the rat viruses have been attempted in Hawaii.

There seems to be little foundation for the extravagant claims made for the successful use of rat viruses. Silver (75, p. 17) reported on the tests of rat viruses conducted by the U. S. Department of Agriculture that, " . . . even the most virulent cultures failed to produce a high percentage of deaths, while the majority of the viruses tested were practically ineffective. Also the disease produced was found not to be contagious, except when one rat ate another. Thus there is little probability of the disease spreading to an appreciable extent."

The most serious objection to the rat viruses is that they are capable of causing serious and fatal food poisoning in humans. Dean (13, p. 148) pointed out this danger in 1929 when he wrote, "Severe cases of food poisoning have been traced to products arising from the growth of the rat organisms which have gotten into food products and grown there. Infected rats, before they die, are likely to spread the infesting organism rather generally about the neighborhood, in fact the effectiveness of this method of extermination depends on spread of the infection."

Leslie (47, pp. 552–562) has submitted ample and convincing proof that these virus preparations could not be distinguished by their cultural characteristics from the classic *S. enteritidis* type which is pathogenic to man. He (idem) has reviewed only recently (1942) the voluminous literature on this subject and has cited many typical cases of food poisoning (gastro-enteritis) directly traceable to these strains of *S. enteritidis*. He summarized his findings by saying (p. 561), "The potential danger to man would appear to lie, not so much in the accidental consumption of the raw virus material itself—although this path of infection cannot be entirely excluded, particularly in the case of children, who are perhaps susceptible to much lower doses than an adult—but in the contamination of foodstuffs, such as milk, cream, custard, cooked meat or pies to be eaten cold, and so forth, all of which form admirable media for the growth of bacteria and in which rapid multiplication may occur under suitable conditions. . . . Moreover, we have reasonable grounds for believing that their range of pathogenicity is wider than this and includes many of the domestic animals, as well as some poultry."

Because rat viruses can be imported into Hawaii only under a permit issued by the Territorial Board of Agriculture and Forestry, the people of the Territory are adequately safeguarded.

CONTROL BY DESTRUCTION OF COVER

The destruction of natural cover should be carried out whenever it is possible. This control measure has been, necessarily, of minor importance in Hawaii because

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*Not to be confused with "Ratinin," a non-bacterial extract of Red Squill, which is manufactured by the Ratin Laboratory, Inc., New York, N. Y.

of the natural environmental factors favoring the growth of wild cover. Stone fences and stone piles accumulated from clearing fields over a period of years are also favorite rat harborage in many regions. Plantations have removed many walls along their roads and utilized them in road construction and for supplying crushed rock for building purposes. However, this is necessarily a slow process at best and in some areas the amounts of rock material are so great that their removal is beyond practical accomplishment.

Any steps to utilize better the waste and forest lands will cause a reduction in the resident rat population; these disturbing factors tend to discourage rats. The partial clearing of some of the natural shrubbery and weeds from gulches and the planting of forest trees, such as eucalyptus and ironwood (Casuarina spp.), which will shade out eventually the ground weeds furnishing rat food, are factors in reducing rat harborage. Examples of low rat populations have been observed along field edges bordering on areas well shaded by eucalyptus and ironwood trees at both Grove Farm and Kilauea Sugar Plantation, where reforestation work has been in progress for some time. It takes several years for this type of control to bring about tangible results.

The clearing of heavy growths of panicum grass (*Panicum barbinode*) out of drains, small gulches and along the edges of fields is of real value in reducing harborage. An excellent practice is to maintain a clean culture strip, 6 or 8 feet wide, around the edges of fields bordering on waste areas. This can be maintained most efficiently by the periodic use of a disc harrow, or by applications of chemical weed spray at necessary intervals. These practices create a barrier of clean ground over which the rats are somewhat reluctant to cross to reach the cane, and afford an easy passage or trail, along which the rat-control operators can place feeding stations for baiting and poisoning. Kilauea Plantation tries to maintain these cleared passageways between their fields and adjacent waste areas as a definite part of their rat-control program.

This same method of creating artificially cleared barriers should be helpful around camps or isolated inhabited buildings in the plague area in the Hamakua district of Hawaii. The exact width necessary for this barrier to become really effective would depend somewhat on local conditions. It is tentatively estimated that 50 to 100 feet of open ground should be ample in most situations. No grass or weeds should be allowed to grow on this cleared space unless these are kept closely cut. Open plantings of trees could remain, provided no brush or rubbish cover is allowed to accumulate on the ground. This clean belt between the cane, and the camp buildings and gardens, would tend to keep the rats back in the cane. Within the camp area regular sanitary inspections should be made to prevent the accumulation of rubbish piles which would offer harborage within the camp itself. These preventative measures would not interfere with active cultivation of usual vegetable gardens around the houses, as long as rubbish and weeds are not allowed to accumulate in undisturbed areas. A buffer trail about 100 feet back into the cane completely surrounding the camp or buildings is considered essential also, to enable both trapping and poisoning to be carried on throughout the year.

Honokaa Sugar Company has been very successful in eliminating rat damage in their macadamia orchards by clearing all ground cover and maintaining this clean

culture by heavy applications of chemical weed sprays* as needed. With the ground cover removed, the rats have retreated to waste areas beyond the orchard. Some poisoning along the border will still be necessary from time to time to prevent damage to nuts falling from trees close to the waste edges.

The destruction of cover, then, should be carried out as a valuable control measure, wherever it is at all reasonable. However, viewing the rat-harborage problem as a whole in the wetter districts of Hawaii, it is economically impossible to make any real progress toward clearing the large areas of wasteland beyond the immediate confines of the cane fields.

Control by Trapping

Trapping is now employed, in a very minor measure, to control rodents near camps or around a harvest field, or to reveal density of rat population in specific areas. Earlier efforts to control rats by trapping were reported by Pemberton (62, pp. 24–25). His results include many detailed records of extensive trapping on the Hamakua coast plantations between 1915 and 1924. He reported that 268,761 rodents were trapped on the Honokaa Sugar Company and the Pacific Sugar Mill Company lands during the six years 1915–1920 inclusive, at a cost of about $10,000 per year. This amounted to slightly over 22 cents per rat caught by trapping. Even with this expenditure, no visible results in reduced cane damage could be detected by Pemberton at the end of this six-year period. According to his Table 4, the average number of rats caught per trap, per month, at Honokaa Sugar Company ranged from a high of 8 for March 1915 to a low of 1.6 for the months of October and November 1924. This figure (1.6) represents the maximum reduction in rat population attained by the poisoning program of that period. However, this condition was not maintained throughout the months of any year. Increasing the number of traps in operation per unit of area gives rise to increased cost per rat, which eventually would become prohibitive. It will be shown later that poisoning is much more economical.

One plantation on Kauai made an effort to control rats by trapping alone during 1937–1938. The trappers concentrated their efforts around the harvest field and caught about 15 rats per acre over the harvested area during the year. They operated 1,500 traps which caught 32,563 rats at a cost of 28.46 man-days per 1000 rats, or at $1.68 per man-day amounting to $.048 per rat. Adding the cost of the traps amounting to 16 cents each we have a total cost per rat of $.055.

Trapping,† then, is an expensive method of catching field rats. Rats multiply

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*The management at Honokaa Sugar Company is convinced that many rats are poisoned as the result of their passing through an area which has been treated with chemical weed spray.

†Garlough (34, p. 5) in reporting the use of traps on an extensive scale to meet an emergency in the pineapple fields of the Hawaiian Pineapple Company, island of Lanai, said: "By use of 24 traps per acre, systematically placed, and left in one location for three nights, it was learned the majority of the rats could be caught. (Trapping in field 5443 for three nights, then retrapping about three weeks later, showed about 4.5 rats to the acre remaining. Another portion of the same field originally trapped for eight days gave, on retrapping, 0.72 rat per acre remaining.)"

This was an example of successful emergency trapping operations while a well-accepted poison bait was being developed for use in the pineapple fields.

so rapidly that any ordinary trapping program may not even keep pace with the normal increase. Our experience corroborates the results from other sugar-producing countries that the expense of trapping, when used alone, is too high in proportion to the benefits received.

If trapping is to be effective, it must be done by operators who are interested in the work, and will almost instinctively set the traps in places that will catch the maximum number of rats. Trapping should be used around homes or villages where it may be considered inadvisable to spread poison, and around special centers of rat population where a definite migration is occurring. For example, by placing traps in a line, at a close interval (6–10 feet apart) around a harvest field, many rats can be caught as they leave their disturbed burrows and scatter in search of new cover.

The number of traps that one man can tend in one day will depend on several factors, among which are the interest of the operator, the nature of the terrain and ground cover, the spacing of the traps, the weather, etc. A good trapper should be able to handle 300 traps per day under average conditions and still have time late in the day to check his traps and reset any snapped ones* and remove any mice. More than 300 traps can be tended in one day if spaced close together in a line around a harvest field.

The coiled spring snap trap with a flat wooden† base is the cheapest and is generally the most effective, although there is an all metal jaw-type trap that works equally well. The wire-cage trap sometimes makes large individual catches. The cage trap should be used around or in a house when it is located in a typhus or plague area. The live rats may then be disposed of without allowing fleas, which these rats may be carrying, to escape. Many traps unless tied down, are carried or dragged into the cane or brush and lost. Placing traps in heavy brush without sufficient marking of the exact location also causes losses.

Fresh coconut cut into squares is the universal trap bait in Hawaii. All species of rats take this bait readily. It may be placed tightly on the trigger and remains good for several nights. Toasted coconut is sometimes used but we are not convinced that this treatment is essential. Pemberton (62, p. 25) reported that bacon has been a good bait at Honokaa. Green avocado, banana, and sweet potato give good results in some districts.

It is very important that all bait should be firmly fixed to the trigger, even if it has to be tied.

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*Spencer (82, p. 2) reported his work in checking a line of 90 Board of Health traps in fields on the island of Maui. He visited these traps at, ". . . 9:00 A. M. one morning and observed that all were in good working condition. He checked them again at 4:00 P. M. of the same day and found the following conditions:

56.4% still remained set and in working order
18.0% were still set but bait was missing
10.6% contained mice
7.5% were sprung with bait intact
3.2% were sprung with bait missing
4.3% contained rats caught from 9:00 A. M. to 4:00 P. M."

100.0%

†These traps may be preserved in good condition by dipping in raw linseed oil or in a heated mixture of linseed oil 75 per cent, and paraffin 25 per cent.

Control by Poisoning

General:

Although poisoning has been the leading method of rodent destruction for many years, it appears that this method has not been an outstanding success in many parts of the world. This has been due in some small degree to ineffective baits, but much more so because the work was carried out intermittently instead of continuously and on a large scale. Special campaigns, which are effective in killing large numbers of rats during a limited time, soon lag and the rats are neglected until they have become so numerous again that they menace our health or food supply.

On sugar plantations it is necessary that a plan of rat control by poisoning be executed efficiently on a large scale. Only intelligent laborers who appreciate the objectives of the work, know its technique and recognize its importance, should be used. The dangers in handling the poison must be fully understood by those who work with it, and precautions are necessary to minimize its danger to others. The selected poison must be reasonably well accepted by the rodents and eaten in sufficient quantity to be lethal to them. The cost of the finished bait after the poison has been incorporated must be within reasonable limits. Many very deadly poisons have an objectionable taste or odor which reduces their acceptance and prevents them from being ideal rat poisons. From a long list of deadly chemicals, only a few qualify as reasonably successful rodent poisons. Undoubtedly the U. S. Biological Survey has been the heaviest contributor to our expanding knowledge of rodent poisons. Our early poisoning work in Hawaii has been, in a large measure, built on the results of their extensive experimental work with strychnine, barium carbonate, phosphorus, arsenic, and extracts of squill. In 1921, Schlupp (71, pp. 9–30) published a most complete compilation of the commonly used rat poisons of that time with a long list of useful formulas. Pemberton (62, pp. 26–37) tried out practically all of these formulas in his work at Honokaa Sugar Company and recorded his observations on the best ones.

History of Poison Work in Hawaii:

W. P. Naquin, former Manager of Honokaa Sugar Company, made the first serious attempt in Hawaii to control rats by poisoning in 1918. At that time the damage was serious, amounting to as much as 30 to 40 per cent injured cane stalks. The readily available commercial rat-poison preparations were only partially satisfactory, being both expensive and subject to very rapid deterioration in the field. During a period of approximately 2½ years (1922–1924) Pemberton (62, pp. 26–27) conducted many separate field tests on rats at Honokaa, as well as 428 separate laboratory tests, using barium carbonate and strychnine in various baits. In addition he carried out other tests with arsenic, extracts of squill, phosphorus, and cyanide of potassium. The results of these tests indicated that the plantation-prepared, strychnine (alkaloid)-treated wheat and barium cakes were reasonably satisfactory and were economical poison baits for field distribution. The most satisfactory formulas (62, pp. 28–29) using barium carbonate and strychnine are repeated here:

Number 1

BARIUM CARBONATE CAKE, RAT X OR HONOKAA CAKE

Barium carbonate (by weight) 1 part
Flour, or preferably middlings, 3 parts

Mix the two together, and enough water to knead into a stiff dough, roll into sheets about ¼ inch thick, cut out small cakes about ½ inch in diameter and dry thoroughly in an oven or by the sun. It is then ready for use. A small portion of 1 cake is usually fatal to any rat.

NUMBER 3

BARIUM CARBONATE OATS

Rolled oats (dry) by weight 6 parts
Barium carbonate 1 part

Mix the two ingredients thoroughly. It can be most satisfactorily done by placing the materials in a tight can and shaking vigorously. This bait has given good results. A modification of this is to use rolled wheat, or wheat flakes (a common breakfast food), instead of the rolled oats. This is best applied in torpedo form. . . . [See Fig. 24.]

The original strychnine formula No. 6 as used by Pemberton (62, p. 36) was after Lantz (46, p. 15) of the Biological Survey. The formula given below has been slightly modified and the directions elaborated by Barnum (6, p. 428) :

MODIFIED STRYCHNINE-WHEAT FORMULA

Procedure	Ingredients	Amount originally indicated by biological survey	Equivalent weight in grams or volumes in cc.
Dissolve by	Laundry starch	1 tablespoonful	9.0 gms.
Boiling 15 minutes	In water	¾ pint	354.0 cc.
Add	Strychnine alkaloid	1 ounce	28.35 gms.
Add	Baking soda	1 ounce	28.35 gms.
Stir and add (keeping hot)	Thick syrup (corn syrup)	1.4 pint	118 cc. or 175.7 gms.
Add	Glycerine	1 tablespoonful	24 gms.
Add and stir	Saccharine	1/10 ounce	2.83 gms.
Thin to proper consistency with	Hot water	(Sufficient to make a creamy paste)	
Pour and mix thoroughly with clean	Whole wheat	13 qts.=22.75 lbs.	10328 gms.
Rinse container to remove paste with and add to wheat	Water	(Approximately) 50 cc.	

Spread treated wheat to dry without further agitation.

The first effective poisoning campaigns in the field at Honokaa Sugar Company were based almost exclusively on the No. 1 barium carbonate formula and the strychnine formula. The rapid deterioration of all rat baits when exposed to rainy weather in the field called for some scheme of protection. Mr. Naquin and F. R. Giddings developed successfully the paraffin-dipped paper "torpedo" for wheat distribution and the paraffin-dipped barium cake. These baits were sufficiently waterproofed to be of practical use in the field (see Fig. 24).

Early in his work at Honokaa, Pemberton (62, p. 27) noted, from observation and records of feeding tests with caged rats, that many rats were immune to strychnine poisoning in any usual concentration and that still other rats refused to eat strychnine-coated wheat. He also found barium carbonate cakes to be very toxic, if rats would eat them. So, as a compromise measure, the Honokaa Sugar Company adopted the policy of alternating the two poisoned baits in successive field applications. Honokaa sent rat-control gangs into all of its fields to distribute a piece of bait "every 10 or 15 feet" in every fifth to tenth line. In this manner, the entire plantation was covered systematically at least once in every 60 days. A similar method of systematic and regular applications of a different poison, thallium sulphate, has been continued and is largely responsible for the good field control which

has been maintained there. This *continuous* persecution of the rat, even if and when the acceptance of bait was poor, has given favorable and lasting results. The marked reduction in the amount of injured cane at harvest has been very noticeable. The percentage of rat-injured cane in the fields, which was estimated at 30–40 per cent before the 1918 poison campaign began, was said to be less than four per cent when the 1929 crop was harvested.

Eventually strychnine was used on Hawaii and on Kauai as the principal poison, while the use of barium carbonate declined. This was due to the difficulty of getting the field rats to eat the barium carbonate baits when so much other food was available. Although barium carbonate baits were very toxic, even in small doses, evidence continued to accumulate to show that these baits were not attractive to wild rats.

However, difficulty developed with strychnine baits also, because certain rats were immune to strychnine* while still others detected the bitter taste of the poison and refused to eat the bait. On Kauai due to this situation an increasing population of wild rats developed which had successfully survived all attempts of poisoning. During 1928 more than 90 tons of strychnine wheat were used by the plantations on Kauai, yet even with this large distribution, rat injury to cane continued with losses tending to increase. In many areas losses amounted to 10 or 12 tons of dead cane per acre left in the field, besides much partially eaten cane which was sent to the mill. The grinding of this soured, rat-injured cane caused heavy losses in sugar due to lowered juice quality.

J. T. Moir, then manager of The Koloa Sugar Company, requested the Hawaiian Sugar Planters' Association to make an investigation of the rat problem on Kauai to determine some better method of control. C. C. Barnum was assigned to this work and began his investigation in September 1928.† His work (6, pp. 431–435) conducted at The Koloa Sugar Company corroborated the earlier work of Pemberton (62, pp. 1–46) and amply demonstrated that many rats were immune to strychnine poisoning. He also found that the rats preferred to eat the packaged strychnine-wheat "torpedoes," which had not been dipped in paraffin, rather than the dipped torpedoes : also that the undipped torpedoes were more toxic. The cause of this reduced toxicity of the dipped torpedoes was due to the fact that paraffin penetrated the poor quality tissue paper used as the wrapper, and coated the enclosed wheat grains. This reduced the acceptance of the wheat by the rats, as well as reduced the digestibility of the strychnine-starch coating on the wheat grains that were actually eaten. Consequently the readily available strychnine content of these torpedoes was not sufficient to kill. It was also demonstrated that many torpedoes,

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*Schwartze (72, pp. 16, 18) in comparing the toxicity of strychnine when ingested by ground squirrels and rats wrote that, "The ground squirrel (*Citellus richardonsi*) is four to five times more sensitive to strychnine than the rat. . . . These animals are killed by relatively much less strychnine because strychnine is far more potent by way of the cheek pouches than when taken into the stomach. . . . This helps to account for the comparative difficulty in poisoning rats."

†McBryde Sugar Company, Ltd., at Eleele, Kauai, cooperated with Barnum in conducting feeding tests with wild caged rats using both strychnine and barium baits. Keith Tester, former agriculturist for that plantation, also conducted many tests with various rat poisons placed in roofing-paper feeding shelters in the fields. All of these studies supported the work that Barnum carried on at The Koloa Sugar Company.

which were not saturated with paraffin, still ran too low (0.14 per cent) in their strychnine content. This was found to be due to the non-adherence of the insoluble strychnine alkaloid when applied in a cold or only slightly cooked starch paste. This was remedied by boiling and stirring the starch mixture for 15 minutes until all of the starch grains were dissolved, at which time the mixture "became extremely adhesive." When strychnine wheat was coated with this cooked starch paste and dried by artificial heat, the strychnine alkaloid could not be easily removed. This change in technique corrected the low toxicity and brought the strychnine content of the rat bait up to a level of 0.25 per cent, which, at that time, was considered near the optimum.* To eliminate the loss of grain due to paraffin penetration of the torpedo wrapper, a high-quality bond paper was substituted for the poor quality toilet tissue.

Barnum (6, p. 434) also conducted cage tests using *barium cake* and reported in part as follows: "No case was observed wherein any rat even nibbled of a barium cake until all other food had been previously removed from the cage. This preparation was apparently very distasteful to rats. It was observed that most rats dying from barium poison were found in or near the water container within the cage. No cake was entirely eaten by rats; lethal results were produced by ingestion of only slight fragments. The marked dislike for preparations containing barium carbonate was a general observation of all tests with this preparation."

Since field rats refused practically all preparations containing barium carbonate and many rats either refused strychnine or ate it without harmful results, the need for a substitute for strychnine was very urgent. In March 1929 Barnum (6, p. 435) conducted the first trials with *thallium†-treated* wheat on the island of Kauai. From the very first trials, thallium-treated wheat was the most readily accepted of all baits tried in cage tests and this poison, fed at 1–1000 concentration, consistently killed all of the trial rats. Tester, at McBryde, also carried on some cage tests with thallium-treated wheat (1–1000 concentration), one torpedo‡ being toxic in each case. The average length of life of a rat after ingesting the poison was three days although some rats lived as long as six days. Here, then, was the first completely effective poison for rats that had ever been tried in Hawaii, and from that time to the present, thallium sulphate has been a very satisfactory lethal agent.

The first field-scale poisoning with thallium-treated wheat torpedoes was made at Grove Farm Company, but other plantations quickly adopted the new poison. The Pacific Guano & Fertilizer Company cooperated with Barnum and commenced the commercial manufacture of the thallium-treated wheat (6, pp. 437–438) using a concentration of one pound of thallium to 1000 pounds of whole wheat made up according to the following formula§:

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*Barnum (5) commented in a report to the Director of the Experiment Station dated 3/25/29, to the effect that baits containing strychnine alkaloid above 0.30 per cent were thought to be too bitter for ready acceptance, and that for an average period of 11 days 5 caged rats refused to eat wheat containing 0.33 per cent strychnine alkaloid. One rat consistently refused to eat these torpedoes for 20 days.

†Throughout this paper the term *thallium* refers to the material which is commercially known as thallium sulphate and chemically as thallous sulphate.

‡Torpedoes averaged 45 to 50 per pound of dry bait at that time—1929.

§This formula for preparing thallium-treated wheat is merely a slight modification of the strychnine-wheat formula previously given. The substitution of thallium sulphate in place of strychnine alkaloid in the formula made a few changes in the technic and equipment necessary.

MODIFIED THALLIUM-WHEAT FORMULA

Ingredients	Small lot amounts	Amounts in grams or cc.s	Ton lot amounts	Procedure
Starch	1 tablespoonful	9.9 gms.	2.0 lbs.	
Water	¾ pint	354.0 cc.	6.8 gals.	Add and boil for 15 min.
Baking soda	1 ounce	28.35 gms.	5.5 lbs.	Stir and boil
Thick syrup	¼ pint	118 cc.=175.7 gms.	2.3 gals.	Stir and boil
Glycerine	1 tablespoonful	24 gms.	4.6 lbs.	Stir
Saccharine	1/10 ounce	2.83 gms.	.8 oz.	Stir
Thallium sulfate (in warm water)		10.328 gms.	2 lbs.	First dissolve in hot water. Mix thoroughly after adding to paste.
Whole wheat	13 qts. or 22 ¾ lbs.	10328 gms.	2000 lbs.	Paste is added to small lots in proportionate amounts and thoroughly mixed.

Treated grain to be spread immediately for drying.

Caution: Do not allow this solution or paste to come in contact with the skin until after drying.

This plan of poisoning with thallium-treated wheat (1–1000) made into torpe-does began auspiciously—with a high acceptance and a heavy kill. However, in time, large numbers of untouched and partially eaten torpedoes began to be observed frequently in cane fields on Kauai, even where rats were still numerous and damage to the cane was continuing. Experimental work was immediately directed toward making the torpedoes more attractive and more easily and quickly found by the rats. Experiments carried out in 1931–1932 by the writer (14, pp. 117–125) using se-lected vegetable oils* demonstrated that corn oil was the best tested and that paraffin alone was the least desirable. These oils did help the rats find the torpedoes, but their waterproofing qualities were low, as compared with pure paraffin. As a com-promise measure, a mixture of one part corn oil and three parts paraffin by weight was applied successfully to torpedoes. This treatment offered the best practical method of combining corn oil for attracting the rats, and paraffin for water-proofing the thallium-wheat torpedoes.

The presence of many untouched or less than half-eaten torpedoes continued to be a problem in the control work. Then reports began to be received that large numbers of hairless rats were present in the fields, and were being caught in trap-ping studies. This condition could mean only one thing—these rats were survivors of sublethal† thallium poisoning (Fig. 23) and were of course, presumed to be bait shy thereafter. It was obvious that many rats were eating only half a torpedo or less and were escaping death. Therefore the concentration of thallium was too low to poison the maximum number of rats. To prove this was true, it was only neces-sary to calculate the amount of actual poison carried in an average torpedo. A tor-pedo containing 10 grams of wheat carried approximately 10 milligrams of thallium (1:1000). This was just barely a lethal dose for a good sized rat weighing 300 to 325 grams, providing he actually ate all of the torpedo. However, if a rat was dis-turbed before his meal was finished or had had a large part of a meal elsewhere

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*Corn oil, sunflower oil, and coconut oil were compared with paraffin as a waterproofing and an attractant for thallium-wheat torpedoes (see heading "Attractants or Lures in Rat Bait").

†A sublethal dose of thallium allows the rat to recover but causes alopecia (loss of hair).

before finding a torpedo, there would be a strong possibility that he would not consume a lethal dose and would survive as a bait-shy rat. Accordingly the concentration of thallium was increased in successive stages to 1-to-666; 1-to-333; 1-to-250; and finally 1-to-200 or less.

Spencer (79, p. 3) of the Biological Survey even increased the poison ratio to as high as 1-to-64. With a concentration as high as 1-to-200, only $\frac{1}{4}$ to $\frac{1}{2}$ of a torpedo was needed to kill. Still smaller portions of a torpedo needed to be eaten to be lethal when the concentration was 1-to-64.

In 1935 several unpoisoned grains were again tested in a series of acceptance trials. The results of these tests* (Doty, 16) showed that, for the areas under study, whole wheat was well down in the list of acceptable grains, with rolled oats and rolled barley ranking first and second respectively. A good grade of rolled barley is generally well accepted by rats, but is wasteful because the hulls, which the rats invariably leave, will retain an appreciable amount of poison. Rolled oats

Fig. 23. A young rat, closely resembling *R. hawaiiensis*, but completely hairless, was captured on Wake Island on July 31, 1940, by Torrey Lyons of Pan-American Airways. It was preserved in formalin to typify the rats which had survived a sublethal dose of thallium sulphate.

From June 22 to July 5, Mr. Lyons had baited over the island with unpoisoned rolled oats followed immediately with thallium-treated oats. For the first two weeks, following the thallium application, it appeared that the kill of rats was at least 90 per cent. From July 20 to 25, many young rats at, or just past, the weaning stage began to appear on the island with little or no hair, except for small, straggly patches on the head and around the ankles.

It was apparent that these rats had survived the poisoning campaign because, at the time of the poisoning, they were still in their nests, and had obtained only a sublethal dose of thallium through the milk while nursing prior to the death of their mothers. At the time when these rats were observed, they were just past the weaning stage and had been forced to leave their nests in search of food.

*The favorite was: (1) sunflower seed, followed in order by (2) rolled oats, (3) rolled barley, (4) corn meal, (5) cracked corn, (6) whole wheat, and (7) milo maize. Sunflower seed was not given serious consideration because we had no facilities for hulling.

were adopted gradually as the leading cereal bait with rolled barley as a second choice. With the advent of hulled rolled oats with excellent absorptive capacity, it was no longer necessary to use a cooked-starch formula. A simplified formula used by the Pacific Chemical & Fertilizer Company is given herewith:

Rolled oats:	630 pounds (7 bags)
Brown sugar:	26½ pounds
Water to make:	8¼ gallons, heated by steam
Thallium sulphate:	Variable according to orders of customers, ranging from 1–100 to 1–250
	(Recommended concentration of thallium: 1–200)

This formula has been used for a number of years, and is the approved one when thallium is used today. The method of preparation of this formula is given in detail in the "Appendix" under Formula No. 1.

To attain a reasonable acceptance of poisoned torpedoes in the field has always been a problem. With the change from whole wheat to rolled oats, and the spraying, sprinkling or dipping of torpedoes with a vegetable oil, the field acceptance for a time was much increased; but even with the liberal distribution of these good torpedoes, rat damage continued to be serious in many areas. It appeared that after a time the surviving rats with uncanny ability detected the poison and discriminated against the white paper torpedoes. While we had a lethal bait, it was not sufficiently attractive to rats and needed some further improvements.

Heavy losses from molds occur when torpedoes are distributed in fields receiving heavy rainfall. It is very difficult to make a waterproof package without reducing its attractiveness to rats. All good baits spoil easily when exposed in the open fields. Ants and cockroaches eat holes in the covering of the torpedoes, thus allowing moisture to enter and spoil the bait very quickly. On any large-scale operation it is impossible to determine how many torpedoes have been eaten; hence a liberal number of torpedoes are generally distributed in order to insure enough for the entire rat population. The result is that large numbers of torpedoes remain in the field to spoil in a few days, and it is common experience to find plenty of moldy torpedoes along the routes of earlier distributions. The most serious problem in the use of this type of poisoned bait is the fact that many torpedoes are only partially eaten or nibbled, instead of being entirely consumed.

From many personal observations it is our belief that, with ample natural food present in a cane field or in adjacent wastelands, many rats are suspicious of any newly discovered food supply and refuse to eat or only nibble at it for two or three days, even though it is of the best nonpoisonous material. Thus it appears that it is not only a case of their detecting the poison in the bait, but also their general suspicion of any new food supply regardless of whether or not it is poisoned. If this is the actual situation, poisoned bait placed directly in the field very frequently is merely sampled. Large numbers of rats, then, may not get a lethal dose the first time they nibble a torpedo, and the resulting discomfort renders them definitely bait shy. Perhaps they also even warn others of the danger. These defects were partially overcome as the concentration of poison was progressively increased to 1-to-100 and 1-to-64 as previously mentioned. However, each increase in the poison concentration was subject also to a probable diminished acceptance due to increased detection of the poison until a practical stalemate finally resulted.

This was the situation in the rat control work when the prebaited feeding-station

method was tried out on an extensive scale during 1936 and 1937. This method offered another tool to be added to our "bag of tricks" and widened our choice of means with which to fight the rat under different environments.

Beginning with 1938 the use of a systematic plan of baiting and poisoning of field rats, at designated specific feeding stations, became an accepted and successful practice on most rat-infested plantations. Since that time direct torpedo poisoning has declined in importance until it is used only in emergencies under special conditions* or as a stopgap until the regular and systematic prebaiting method can be used.

Direct Poisoning Without Previous Baiting:

All of the rat poisoning work in Hawaii from 1918 to 1938 had been carried out by direct poisoning without previous baiting, and since this method is still of value under certain conditions, it is appropriate that the most effective methods of direct poisoning should be recorded along with some of the conditions necessary for success.

KINDS OF BAIT:

Rats generally will accept moist baits better than dry ones, and fresh perishable foods are preferred to preserved substitutes. Boulenger (8, p. 6) has summarized a large number of palatability tests, conducted in England with rats, covering 27 different kinds of food stuffs, including bread, meat, and fish of various kinds, vegetables, oils, and fruits. His table shows bread to be the food most attractive to caged rats, with oatmeal, tallow, banana, bread soaked in milk, oats (whole), barley, and tripe following in order named.

Many of these baits could be used under certain circumstances but most of them would be too expensive for extensive field use. Dry cereal baits, which can be readily manufactured at a reasonable cost and have good-keeping qualities, have been the chief poison carriers for field-rat control. The most frequently used bait is poisoned rolled oats, although rolled barley and whole wheat have been used under stern necessity. The concentration most generally recommended is one part of poison to 200† parts of grain, although some plantations prefer to make up mixtures as strong as 1-to-100 to be sure of killing any rats which may eat less than $\frac{1}{4}$ of an average torpedo.

Thallium sulphate is still the reliable and successful poison for our cereal baits, but owing to its scarcity, zinc phosphide has now been substituted with equal success. When zinc phosphide is used it may be advisable to increase the concentration of the poison to 1-to-100 for direct poisoning. This bait should be packaged into small units (torpedoes) for easy distribution. A good quality of fiber-spun bond paper cut into pieces $4\frac{5}{8}''$ x $4\frac{7}{8}''$‡ makes excellent wrappers which can be folded or

*See heading "Conditions necessary for success" for a discussion of these special conditions.
†See "Appendix" for thallium sulphate and zinc phosphide formulas.
‡A ream (500 sheets) of 28"x 34" paper cut to torpedo wrappers of $4\frac{5}{8}''$x $4\frac{7}{8}''$ makes a total of 21,000 wrappers. The paper cuts 6 times on the 28-inch side, spaced $4\frac{7}{8}''$ and 7 times on the 34-inch side spaced $4\frac{5}{8}''$.

twisted to carry a small spoonful of grain each (Fig. 24). It is possible to make smaller torpedoes out of 4″ x 4″ papers if they are folded instead of twisted to close them. The amount of grain contained in each torpedo should be such that about 100 torpedoes may be made from each pound of rolled oats.

As a convenience to prepare torpedoes more rapidly, Barnum (6, p. 441) recommended a simple "shaper." This device consists of a 1″ x 6″ cylinder of wood attached in a vertical position to a board platform. The upper end of the cylinder should be rounded off like the end of a broomstick. The sheets of paper are placed directly over the rounded top and pressed down allowing the paper to shape over the wood cylinder as the hand is slid down and around it. "This produces a cup-shaped receptacle into which the measured dose of rat bait is poured and the paper then twisted to form the torpedo." After the torpedoes are made up, they should be sprinkled or sprayed with enough of a desirable* oil to make them attractive as well as somewhat waterproof. While paraffin is a good waterproofing material, we no longer recommend it as it has proved to be very distasteful to rats—it probably sticks to their teeth.

The sausage type of meat baits using thallium, as developed by the Biological Survey while studying the Hawaiian rat problem during 1936–37, is undoubtedly one of the best accepted. Spencer and Jordan (36, pp. 3–9) and Spencer (80, pp. 2–10) reported that fresh hamburger sausage and cooked salt pork sausage ranked

Fig. 24. The torpedo form of poisoned bait is made by wrapping a teaspoonful of dry, poisoned rolled oats in a small square of bond paper. Some oil attractant is sprinkled or sprayed over the torpedoes before they are distributed to selected places. Under special conditions for short infrequent periods, this form of poisoning may succeed. After Pemberton (62).

*Usual order of preference by rats: Corn oil, raw linseed oil, coconut oil. Raw linseed oil is probably the best waterproofing agent of the list. It is often accepted as well as corn or coconut oil, and in some instances even better.

equally high in acceptance tests on Kauai. Mixtures of cooked salt pork, cracked barley and rolled oats proved very acceptable also.

According to Spencer (36, p. 5), the adding of common table salt at the rate of one ounce to each four pounds of meat sausage seemed to raise the acceptance rate at Grove Farm but at Kilauea no difference was noted. Most of these sausage meat baits will not need any special attractants.

There are several practical objections to the use of sausage meat baits in large-scale operations:

(1) They spoil quickly and the souring of the bait definitely reduced its accept-ance. Spencer and Jordan (36, p. 6) found that cooked salt pork with some barley and oats was accepted one third better than the same material which was allowed to sour.

(2) Meat baits (poisoned with thallium) are attractive to dogs, cats, and mon-gooses in the immediate region, and their consumption will kill these animals.

(3) Wet baits can not be used successfully with zinc phosphide on account of its rapid deterioration in the presence of so much moisture.

(4) Costs are invariably higher for such baits, due to the original cost of ingre-dients plus the extra labor and equipment necessary to manufacture.

Fresh coconut cut into ½-inch cubes and poisoned with zinc phosphide has been used extensively by Kaeleku Sugar Company as successful auxiliary bait following cereal bait used in the prebaiting program. These coconut cubes have been readily accepted even by rats that had apparently refused rolled oats bait. The method of preparing this effective bait, using zinc phosphide and lime on coconut cubes, is dis-cussed under the subject of "Zinc Phosphide" in the "Experimental Studies in Rat Control."

DISTRIBUTION OF BAITS: /

Torpedo baits are generally distributed from bags hung from the shoulder while the operator either walks or rides on horseback. Pemberton (61, p. 195) reported that at Honokaa it was the policy to drop a torpedo "every 10 or 15 feet" in every 5th to 10th line of cane. In big cane it would be necessary that trails be kept open every 100 feet to allow the operator to walk through and throw the torpedoes on both sides, endeavoring to cover a strip of 50 feet on either side. These trails would be very expensive to maintain at any time, and with the present labor shortage they would be impossible.

The "slingshot" has been used in some instances to throw the torpedoes some distance into big cane. This method of distribution causes much waste because many torpedoes lodge in the cane leaves instead of reaching the ground. The opera-tor may distribute torpedoes from horseback around the edges of waste and pasture lands. Most of the bait should be scattered where the rats are most likely to be living, such as in stone piles, thick brush cover, rocky banks, etc. In studying rats on Kauai, Jordan (36, p. 9) noted " . . . that the rats take the baits the best and trap the easiest in gulches." Extra torpedoes should also be placed where fresh damage to cane is noted. Rats invariably return on successive nights to the same area to continue their destruction. Very often the same stool or even the same stick is chewed for several consecutive nights. These spots should be revisited to see if torpedoes have been accepted and the damage checked. In irrigated fields the irri-

gators should be supplied with torpedoes to be applied to any damaged spots they may discover. The number of torpedoes necessary to cover one acre varies with the kind of terrain, the age of cane, and the suspected density of the rat population. However, two hundred baits per acre should be sufficient for most conditions.

When an area has been treated for the first time, it is essential that a second application be made within from ten days to two weeks. This is specially important along forest borders or newly harvested areas where migration is known to be occurring. It is very necessary that the rat-control program of a plantation be so organized, preferably under one responsible man, that all fields are baited systematically and regularly on a year-round basis like any other essential field operation. The number of rounds of poisoning per year will vary according to the density of the population and the susceptibility of the area to reinfestation from outside sources. Four rounds per year will not be too frequent for areas of moderate reinfestation and six rounds should be provided in heavily infested areas. Frequent inspections of the interior parts of cane fields or suspected danger points should be made to determine if fresh damage has occurred. Any new areas of damage should be treated promptly. Some trapping should be done in selected areas in order to keep informed on the density of the rat population and the efficiency of the control measures being applied.

ROTATION OF BAITS:

When and if direct poisoning by torpedo baits is to be used as a general field practice, it is strongly recommended that a rotation* of baits be carried out as one of the most essential procedures. Judging from the gradual decline in acceptance of a single kind of poisoned torpedo used previous to prebaiting, continued high efficiency of a poisoned rat bait over a period of time probably depends largely upon the number of times a particular bait-formula type is used.

CONDITIONS NECESSARY FOR SUCCESS:

It is the purpose of this paragraph to try to evaluate the conditions under which direct poisoning without previous baiting may be used in the most effective manner. With the continued success of the prebaiting method over large areas of cane, we believe that this method should be preferred for systematic control. However, there are times and conditions when the necessity for immediate action is imperative. The system of prebaiting entails a certain definite delay before poisoning, which may allow time for some rats to infiltrate through the line of stations before the poison is applied. Under these conditions the direct application of poisoned bait should be very beneficial even though the acceptance might be low. This bait could be applied either as torpedoes or as loose poisoned bait placed in feeding stations if these are already in the field. This emergency measure would act as a first line of defense to stop as many of the invaders as possible during a period of great activity. Systematic "mopping up" operations should quickly follow, using the more efficient

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*On one Kauai plantation the development of a population of bait-shy rats, which occurred during the period previous to prebaiting when even oat torpedoes were refused, could have been prevented by a rotation of baits repeated at frequent intervals (less than two months). The rats had become so bait shy that serious damage occurred with untouched torpedoes scattered everywhere.

baiting and poisoning method to kill the rats that have taken up more or less permanent residence in or near the cane. We believe the combination of the two methods should be very effective in stopping a serious migration from waste areas into cane —migrations like those which occurred during the month of December 1942 in the Hana district.

Another situation in which direct poisoning with torpedoes should be effective is when there is an active migration from a harvest field where rat food has become scarce. The areas immediately surrounding a harvest field are a preferred place to distribute a liberal supply of torpedoes. As the cane is removed from the field both the food supply and the cover are reduced, and any rats which try to stay in stone piles in the field will be more susceptible to direct poisoning. But as the young cane gets started, a regular systematic period of baiting and poisoning is recommended to catch the surviving population as it becomes static.

The Prebaited Feeding-Station Method:

DESCRIPTION AND PROCEDURE:

The current practice of poisoning on all plantations is by the *Prebaited Feeding-Station Method*. There has been little change in this method from that given in the original paper in 1938 (Doty, 22). Briefly, the plan consists in feeding rats *unpoisoned* grain in specific places until a large part of the surrounding rat population has discovered the new source of food and has formed the habit of visiting these feeding places. This period of feeding unpoisoned grain is called the baiting period. As soon as the rats have acquired the habit of visiting these stations regularly and have become accustomed to the surroundings and gained confidence in the food supplies, the unpoisoned grain is removed and *poisoned* grain substituted. This is called the poisoning period. When the rats return the following night, they eat a lethal dose of the apparently identical food without suspecting the change.

The normal functioning of a feeding station is illustrated by the personal observations of Dr. F. X. Williams of our Entomology department who has reported on his operation of a prebaited feeding station at his home. The feeding station was situated about 10 feet from the ground on top of a fern house partially surrounded by vines and shrubbery. One open end of the station's cover faced toward the observer's vantage point about 20 feet away and the other toward a bright moonlit sky so that rats coming to eat were clearly observed as silhouettes.

After several nights' exposure of unpoisoned oats (baiting), a rat habitually visited the station each night about or a little after dusk. This rat usually stayed from 10 to 15 minutes. Sometime after the first rat had left, another one would appear and repeat the procedure. Only one rat was observed to feed at the station at the same time. The rat appeared to pick up one grain at a time, raise its head to observe and then eat the grain. (A rat habitually picks up a single grain of rolled oats or barley with its mouth and, holding the grain edgewise by its fore feet, it nibbles along the edge of the grain.)

On the night the poisoned bait was substituted, the rat came as usual and stayed at least 10 minutes indicating that the poisoned grain was accepted and eaten in a normal manner. The amount of poisoned bait eaten during the night indicated that several rats had visited the station. After the consumption during the first night, no further poisoned oats were taken. Some days later a dried mummified carcass

of a black rat was found in the vines about eight feet from the ground and about 20 feet from the fern house.

It is advisable to make the substitution from unpoisoned to poisoned bait over a large area on the same day so that there will be the fewest possible unpoisoned rats able to observe the plight of their less fortunate companions and perhaps become aware of the change in food. If some unpoisoned bait is left in the area* it is highly probable that rat travelers will concentrate on this food, and this may help them to detect and refuse the poisoned bait at nearby stations. All stations in a given area should be poisoned on the same day whether they were active or inactive during the baiting period. Even the most wary rat cannot predict when the change from unpoisoned to poisoned bait will be made as this depends on such circumstances as the weather, or the day of the week.

This plan is effective, even following a recent direct poisoning with loose grain or torpedoes, irrespective of the bait used. At present rolled oats stand out as the most efficient and economical bait. Owing to the large quantity of oats being consumed at the time the poisoned oats are substituted, high concentrations of the poison are not necessary because the rats are then eating freely, instead of cautiously nibbling or sampling a new food. It has been noted in all tests using prebaiting that the consumption followed a definite pattern. For the first few days (two or three) there would be little or even no consumption of the new food supply, but in less than a week the increased consumption would indicate that a large clientele had been built up. This progressive increase in consumption remains the most vital factor in the success of the plan; for without this increase there would be little or no advantage over direct poisoning. After the consumption of unpoisoned oats has reached a peak, which it normally does in a group of evenly distributed stations in six or eight days, the curve will tend to level off with only small fluctuations thereafter unless upset by new migrants from further outside of the original circle. However, when a line of stations borders on waste or forest lands where a seemingly inexhaustible population of rats reside, the curve may continue to rise over a considerably longer period.

It is impractical and expensive to continue to feed the rats unpoisoned grain for more than six or seven days, so poisoned bait should then be applied to kill off all station clients. In certain instances it may be advisable to poison after five days instead of six to make a maximum reduction in a large population with a minimum cost. In an area subjected to heavy migration from wasteland, the whole process of baiting and poisoning should be repeated at frequent intervals. This subject is treated in detail under the heading, "Interval Between Poisoning Cycles."

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*In Experiment I, Grove Farm Company (Doty, 22—Fig. 19), there were several stations located along the pasture fence and the center road which had remained inactive all through the 8-day baiting period. On the day that poisoned bait was applied, unpoisoned grain was allowed to remain in these previously inactive stations with the result that they became very active during the 3-day period when all of the rest of the stations were poisoned. These stations, too, were poisoned for the following two days but very little bait was eaten. Then following the poisoning period all stations were again filled with unpoisoned grain to check up on the survivors. These same stations continued to have *survivors*, which strongly suggests that the rats originally detected something wrong at the poisoned stations and traveled from station to station nearby, until they found a pan containing food exactly like that with which they were familiar.

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EQUIPMENT:

Much of the field equipment now in use is the same as originally manufactured or purchased by the plantations when they first took up the prebaiting method.

The original portable feeding station consisted of a small, tinned baking pan (7 x 7 x 1¼ inches) placed under a curved cover, shaped like the tops of the old

Fig. 25. Materials for twenty feeding stations ready for distribution in the field. After Doty (22).

covered wagons and made of a 15- x 16-inch piece of light (28-gauge) galvanized iron. To curve the covers into a half cylinder they may be shaped over a piece of 6- or 7-inch pipe or by a tinsmith's roll-forming machine. The square, almost vertical-sided baking plans are preferable to round sloping-sided pie pans, as their use practically eliminates spilling and consequent wasting of the grain. Since the

Fig. 26. Same materials illustrated in Fig. 25 showing covers placed on the shoulder as an alternate carrying position. After Doty (22).

covers soon discolor and blend into the landscape under exposure to the weather, it is advisable to paint at least an orange-yellow or red stripe along or across the top to assist in finding them. Painting the entire cover—which tends to increase the weight—is not necessary. When both pans and covers can be nested together in compact form, they are more conveniently handled and distributed in the fields.

Fig. 27. Filling the pan with rolled oats. One cupfull (one-quarter pound) is a convenient amount of unpoisoned grain. After Doty (22).

One man can carry at one time the complete equipment for 20 stations (see Figs. 25 and 26). This consists of 20 pans weighing six pounds, 20 covers weighing 26 pounds, and at least five pounds of grain in a waterproof canvas bag slung over the shoulder. The covers may be carried under the left arm or on the shoulder while the pans may be carried in the right hand, or in a separate bag or in the bag with the grain (see Figs. 27 and 28). The rubbing of raw linseed oil or any other oil
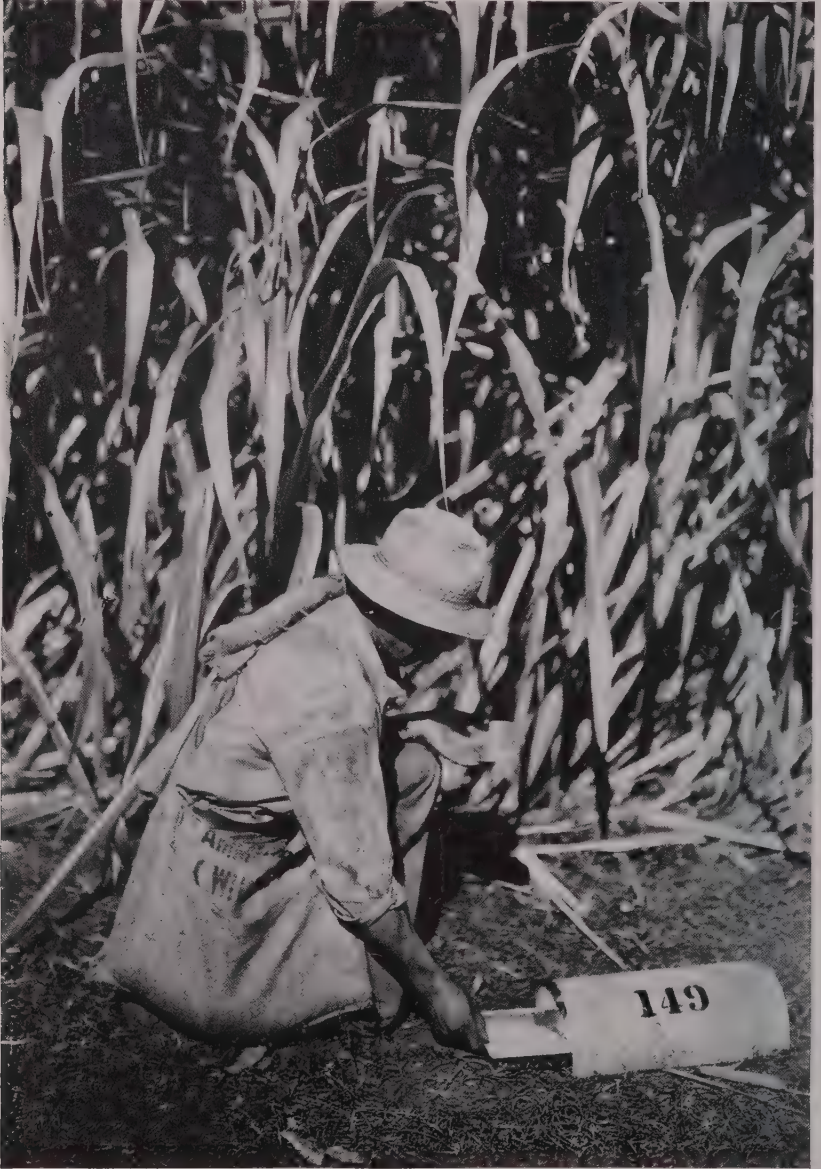
Fig. 28. Inserting the pan under the cover. After Doty (22).

attractant on the inside of the covers before they are placed in the field had to be discontinued because this procedure caused the covers to stick together while they were nested, and refuse accumulated on the oiled surfaces.

Permanent feeding stations, made up to be left in the field around stone piles or along "buffer" trails cut 200–300 feet outside of field edges, have been successfully used. Since these will seldom be moved, they may be made of materials and in forms which disregard lightness and convenience in handling, but they should retain waterproof and watertight features which will keep the bait dry.

BAITS:

General Considerations: The same general considerations in the choice and use of baits apply to prebaiting as those which have been partially discussed under baits for "Direct Poisoning Without Previous Baiting." It is necessary that the selected bait be economical and readily available in sufficient quantity and remain palatable to the rats for some time. All protein foods are readily accepted by field rats, but high-protein foods such as cheese and raw meats are obviously uneconomical and hard to handle in large-scale field operations.

Of the common dry cereals, bulk rolled oats have proved the favorite in our preference tests (Doty, 22, p. 41). A good grade of rolled barley can serve as a substitute but it may prove wasteful and ineffective because the hulls, which the rats invariably leave, will retain much of the poison used. Rolled grains have distinct advantages over whole kernels in being more acceptable to the rats, and in having better poison-absorbent properties and greater surface area for poison adherence.

Under extremely wet conditions, rolled oats, placed in stations surrounded by dense weed growth where there is poor circulation of air, will mold from condensation of moisture in three or four days. Some loss will occur from this cause in the less active stations during periods of high humidity and frequent rains. Spencer (82, p. 4) of the Fish and Wildlife Service, formerly Biological Survey, has reported benefit from the use of one per cent by weight of sodium sulphite in rat bait as a protection against spoilage. However, neither sodium sulphite nor benzoate of soda have received much attention, mainly because of the extra trouble to add the materials and redry the bait. When zinc phosphide is the lethal agent in rat bait, no water is used in the formula, so no practical way of introducing the mold deterrents has been tried. The problem is circumvented to a high degree by making certain that the bait is very dry when it is taken to the field. Kaeleku Sugar Company is now drying its oats in special trays over the factory boilers before adding the zinc phosphide powder suspended in oil to make their poisoned bait. This helps to overcome the tendency of their zinc-treated bait to deteriorate. (See discussion later in this paper under the subject of "Zinc Phosphide.")

Concentration of Poison in Baits: The minimum lethal dose (M.L.D.) of thallium sulphate has been studied by several investigators. Munch (56, pp. 20–21) reported that:

The minimum lethal dose of chemically pure thallium sulphate was found to be 25 milligrams* of thallium, or 31 milligrams of thallium sulphate per kilo [of body weight] when fed

*"Since thallium sulphate has the formula Tl_2SO_4 and contains 81 per cent of thallium, 1.24 grams of thallium sulphate were taken as the equivalent of 1 gram of thallium." (Munch 56, p. 15.)

to rats. . . . Thallium is among the most toxic substances recommended for rat control; comparative tests with other rat poisons by the same feeding method give the following minimum lethal doses:

	Mg. per kgm. of body weight
Thallium	25
Strychnine	20–25*
Arsenious oxide	100
Red-squill powder	250
Barium carbonate	750

Later studies by Garlough and Spencer (35, p. 4)˙ indicated 30–31 milligrams of thallium sulphate to be lethal, which corroborated the work by Munch. This disregarded any possible neutralizing action of food acids.

To visualize better what this means in practical terms, the following tabulation of theoretical killing power of the various concentrations of poisoned oats has been prepared.

TABLE I

THEORETICAL EFFICIENCY OF THALLIUM SULPHATE EXPRESSED
IN WEIGHT OF RATS KILLED

Concentrations of thallium sulphate.................	1–64	1–100	1–150	1–200	1–250	1–666
Milligrams of thallium sulphate per pound of oats...	7087	4536	3024	2268	1814	681
Weight of rats that should be killed per pound of oats................... (kilos)	236	151	101	76	61	23
(pounds)	520	333	222	168	133	50

These weights are calculated on the basis of 30 milligrams of thallium sulphate as a lethal dose for 1000 grams of body weight of rats.

Example: Taking the 1–100 concentration we have:

$$1 \text{ lb. oats contains } \frac{4536 \text{ mg. thallium}}{30 \text{ mg. (M.L.D.)}} = 151.2 \text{ kgs. or } 332.6 \text{ lbs. of rats}$$

This is equivalent to approximately 450 adult *Rattus norvegicus* (Erxlelen) or 2,000 *Rattus hawaiiensis* (Stone). The average weight of an adult *norvegicus* is approximately 325 grams (.7 lb.), and of little *R. hawaiiensis* 60 grams (.13 lb.).

TABLE II

WEIGHT OF RATS KILLED BY 1, 2, AND 3 GRAMS OF POISONED OATS
AT VARIOUS CONCENTRATIONS

Concentrations of thallium sulphate	1–64	1–100	1–150	1–200	1–250	1–666
1 gm. oats should kill............... (pounds)	1.1	.7	.5	.4	.3	.1
2 gms. oats should kill.............. (pounds)	2.3	1.5	1.0	.7	.6	.2
3 gms. oats should kill.............. (pounds)	3.4	2.2	1.5	1.1˙	.9	.3

The last column of Table II shows that three grams of grain of the old 1–666 formula would kill only a small half-grown rat weighing .3 pound. Some old formulas were even weaker (1–1000) and proportionately more bait was required to kill. We may calculate that 2½ grams of oats of 1–250 concentration will kill a large rat weighing three-quarters of a pound, which is about the average for an adult Norway rat, the common rat on Kauai. If the concentration is increased to

*In a later paper published in 1942, Munch (57, p. 22) reported the M.L.D. of strychnine to be 10–15 mg. per kilo instead of 20–25 as given in the above table.

1-200 only two grams of oats are required to kill a rat of about the same size, and if the concentration of thallium is further increased to 1–100 only one gram is required. For all practical purposes a concentration of 1–200 should be sufficient for the prebaited feeding-station method when the rats have developed the habit of eating freely, for under these conditions the rats will eat much more than the minimum lethal dose (Fig. 29).

Very little work has been reported thus far by investigators on the minimum lethal dose of zinc phosphide. Work by the U. S. Fish and Wildlife Service indicated that it is equal to thallium sulphate in lethal properties. Silver and Garlough (77, p. 16) list the M.L.D. of both thallium sulphate and zinc phosphide as 25 milligrams per kilo of body weight. The toxicity of these two poisons for rat control and the proportions to use in bait material as suggested by Silver and Garlough are given below :*

Kind	Lethal Dose		Proportions for 90% Efficiency		Bait ratio poison/bait
	Mg/kg^1	Killing time (*hours*)	Poison (*ounces*)	Bait (*pounds*)	
Thallium sulphate	25	72	1	4	1/64
Zinc phosphide	25	6	1	6	1/96

[1]Milligrams per kilogram of body weight.

We have not conducted special minimum lethal dose studies on zinc phosphide but our cage tests and prebaited feeding-station experiments in the field indicated

Fig. 29. An idea of the amount of rolled oats represented by one, two, and three grams (actual size). The weight of rats killed by these amounts of poisoned oats is shown in Table II. After Doty (22).

*Abstracted in part from Table II (77, p. 16).

that zinc phosphide in concentrations equal to thallium sulphate was equivalent in acceptance and killing power. However, late in 1942, the Fish and Wildlife Service conducted a lethal-dose test of zinc phosphide on white rats at Amherst, Massachusetts, which indicated about 75 mg/kg to be the M.L.D. instead of 25 mg/kg as indicated above. More work will have to be done on zinc phosphide before the exact lethal dose can be established. But this uncertainty need not limit the usefulness of zinc phosphide in the prebaited feeding-station method of poisoning the field rat. The exact minimum lethal dose is of less importance when prebaiting is practiced than under direct poisoning because the rat will always eat more than the minimum requirement of a 1:200 formula when baited before being poisoned.

The outstanding difference between the action of these two poisons under the prebaiting method is the length of time required to kill the rat after eating the lethal meal. The rat that eats the zinc phosphide is dead long before the one that eats the thallium sulphate is even sick.

While it cannot be stated exactly what the average consumption of oats by a large rat may be under field conditions where natural food abounds, it is probably between three and five grams at a time. Thus, taking three grams of 1–200 poisoned oats as an average consumption in the field, one pound of this material should account for 151 full-grown rats. If the average consumption should reach four grams each, one pound of poisoned oats will still be sufficient to kill 113 full-sized rats. On the above assumption, increasing the concentration of thallium (or perhaps zinc phosphide) merely gives an overdose—a margin of safety or insurance—and does not necessarily increase the number of rats killed per pound of poisoned bait. In dealing with high concentrations such as 1–64 or 1–100 we have, in addition to the greater cost of the poison, the increased possibility of the rats detecting the poison in some way, as was suggested by the results of Experiments 24, 25, and 37 (see heading "Detection of Toxic Substances in Food").

Attractants for Grain Baits: The results of experiments by many workers, which are reviewed under the subject, "Attractants or Lures in Rat Baits," show that some oil attractant may be used with benefit in all cereal rat baits. In the prebaited feeding-station method, however, the kind of oil appears of less importance than with the torpedo method, as long as some attractant is used to help the rats find the station quickly.* The best vegetable oil attractants found thus far are corn oil, raw linseed oil and coconut oil in that order.

The oil is mixed with the bait in quantities sufficient to flavor it and make it attractive to the rats. When using the sweetened thallium-treated oats prepared by the Pacific Chemical & Fertilizer Company, the amount of oil is not critical since it is not the poison carrier.

The Lihue Plantation Company has applied successfully finely powdered thallium suspended in oil to rolled oats. They experienced no difficulty in securing an even distribution as well as good adherence of the poison to the rolled oats when the mixing was done in a small cement mixer operated by an electric motor. They used three quarts of oil per 45 pounds of rolled oats. (See formula No. 2 in the "Appendix.")

In actual tests three quarts of oil have been found sufficient for 100 pounds of

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*It is entirely possible that a cup of fresh rolled oats in an open pan may also give off some pleasing aroma of its own.

rolled oats. Kaeleku Sugar Company has recently adopted this amount of oil for their standard zinc phosphide mixture, though it seems to be near the minimum to give satisfactory adherence of the zinc phosphide to the oats.

Benefit from Sweetening the Poisoned Bait: "Sugar, or treacle, has been added to bait and poisoned food for rats for centuries [according to Hovell 40, p. 137] under the belief that it makes it more attractive. . . . " That this belief now has a basis in scientific fact has been established by the recent work of Richter and Campbell (69, pp. 31–46). They demonstrated that rats can distinguish and show a taste preference for sugars in rather dilute solutions. Laboratory rats recognized a difference between sugar solutions and distilled water in concentration per cents as follows: (1) Maltose* 0.06, (2) glucose 0.20, (3) sucrose 0.57, and (4) galactose 1.60. Rats indicated their greatest preference for maltose, followed by glucose and sucrose, but only a slight appetite for galactose, while lactose was not accepted. Solutions of these sugars in concentrations near 10 per cent received the greatest preference. This agrees closely with concentrations of sugar solutions commonly used by humans to sweeten beverages.

The results of Experiment 32 reported previously (Doty, 22, pp. 50–53) indicated a reliable and consistent loss for the unsweetened oats ranging from 25 to 30 per cent below the standard sweetened formula.

It is also interesting to record again that a station-to-station comparison of consumption for the three periods of feeding shows that out of a total of 193 paired records, 116 favored the sweetened oats, 46 favored the unsweetened and 31 were exactly even. These data indicate that the present sweetened poisoned formula using thallium† should be continued without change.

Coloring Agents to Identify Poisons: Coloring agents may be added to poisoned bait to distinguish it easily from that which is not poisoned. For thallium-treated oats, methylene blue is recommended. Solutions of one tenth of one per cent methylene blue at the rate of 40 cc. per pound of dry oats give a very satisfactory color to the treated grain. Only 5 to 10 per cent of the poisoned grain needs to be colored; this is mixed throughout the remainder.

Zinc‡-treated oats, which already have a sooty appearance, probably need no further identification; but in case coloring is desired, use an oil soluble dye, such as Sudan III (red) or Sudan IV (red) to avoid adding water to the formula. For further discussion of the coloring of poisoned grain refer to subject titled, "Use of Coloring Agents to Identify Poisoned Baits."

PROCEDURE IN THE FIELD:

Distribution of Stations: The necessary quantity of the equipment previously described, together with a supply of unpoisoned oats should be taken to the field and distributed at strategic points. One distributor may take a load of approximately 20 complete stations and proceed to set out complete stations in selected places; or if two men are working together, the first man may carry up to 40 covers only and

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*The attractiveness of maltose sugar could be due, in part, to its odor as well as its taste.
†For the standard thallium formula see "Appendix."
‡Throughout this paper the term *zinc* refers to *zinc phosphide.*

distribute these along a designated route to be followed by the second man who carries the pans and a bag of grain and who empties a cup of grain into each pan and places it under a cover. For average conditions along roads, level ditches or trails within a field, the stations may be spaced 75–100 feet apart; this results in the placement of about four stations per acre. They should be spaced roughly equidistant, but the exact spot should be determined by the ease and speed of setting the pans upon fairly level ground. The stations should not be placed in a depression or ditch as heavy rains may flood such areas and fill the grain pans. Stations function best where good cover is offered along the edges of or slightly within the cane or brush. No attempt should be made to hide them in the cane, although they should be off the trail sufficiently to avoid tripping over them during subsequent visits.

The stations should be spaced much closer (45–50 feet apart) when the cane borders on a gulch or other wasteland with heavy growths of grass, brush or other good shelter (*i.e.,* panicum grass, honohono, lantana, guava, etc.). While conducting field trials we have observed many well-worn rat trails running through the grass directly from the gulch or brush cover into the cane. The stations should be placed closer together where these conditions prevail, to try to intercept this direct rat traffic. A closely spaced line of stations along the edge of a rat-infested gulch or other waste adjacent to very young cane has proved to be an ideal arrangement, and has greatly reduced or in some instances entirely eliminated the necessity of placing stations inside the field at a later date, after the cane had closed in. This procedure of concentrating materials and effort on the borders while the cane is young has reduced greatly the average number of stations necessary per acre for the whole field. This scheme if repeated at frequent intervals as the cane grows, depending of course on the amount of reinfestation, will effectively and economically protect the entire field up to harvest. Kilauea Sugar Company's excellent control of rats at very low cost has been due to the early, concentrated and continuous poisoning at all borders. This has made it possible in most fields to omit poisoning operations in the centers of large areas of big cane. If early neglect has allowed large areas of big cane to become rat infested, then trails will have to be opened which should not be more than 250 feet apart so that lines of stations can be placed within the field. It will also be necessary to have a trail or trails opening a passage way to stone piles or other waste areas within a field. The greater the distance between stations, the longer must be the period of baiting before changing to poisoned oats in order to insure adequate control. The route taken while placing these stations should be noted by the operator so that he can revisit them easily after the proper interval. Carelessness in this simple detail is responsible for many lost stations and added expense to replace them.

Filling the Stations (see Figs. 27 and 28): On the first trip each station is placed and a measured amount of unpoisoned oats poured into each pan. A convenient amount was found to be one-fourth pound which exactly filled a kitchen measuring cup or a one-pound flat pineapple tin. In special cases where severe fresh rat damage is observed two cups may be left on this first round.

There is so little acceptance during the first two days of baiting that no useful purpose is served by inspecting the stations so soon, but after four days an inspection should be made to renew the oats, as the rats will have begun to feed more confidently. If at this time the grain is dirty, moldy or otherwise unattractive it should

be removed, and later weighed and discarded. Sufficient unpoisoned grain should be placed in the pans during this visit to assure a supply for another two or possibly three nights remaining before poisoning, otherwise the efficiency may be reduced. Consumption of unpoisoned grain during this last period of two days will generally exceed the total eaten during the first four days. The second visit to renew the bait may be made after three days instead of after four days, but in this event a less accurate estimate of the future consumption is likely to be made. Hence to be sure of ample food for the remainder of the baiting period, the amount left should be very near double the amount consumed during the first three days.

The third visit should follow within two or three days, and at this time any remaining unpoisoned oats should be removed and the poisoned oats substituted. This poisoned grain should remain in the pans at least three days before the stations are removed from the field on the fourth and final visit. As shown elsewhere in the experimental evidence (see "Experimental Studies in Rat Control") less than one per cent of the total poisoned grain eaten was normally taken after the third night. The stations may be left four days or more to catch this final one per cent if it is not urgent to remove them sooner.

The amount of poisoned oats that will be consumed bears a direct relation to the amount of unpoisoned oats previously eaten. Following a six-day baiting, the normal amount of poisoned bait that will be consumed will be around one pound of poisoned oats for every five or six pounds of unpoisoned oats, provided there were no empty pans. A low ratio will be obtained if there were many empty pans during the baiting period, and therefore it will be unreliable. If numbers of new rats are migrating into the area during the baiting period the ratio may also be low due to the late arrivals feeding only one or two nights before poisoned bait was applied. Therefore poisoned oats placed at the rate of one third of the amount of unpoisoned oats consumed during a six-day baiting period is more than sufficient to supply all rats visiting the pans. It is desirable that a very small amount of oats be left at the end of the poisoning period to prove that scarcity of poisoned bait was not a limiting factor of its consumption.

In most plantation areas the rat population has been so reduced that a standard minimum application of one cup of unpoisoned oats followed by one fourth or one third of a cup of poisoned oats, uniformly to all stations will be sufficient for each period of baiting and poisoning. However, in some plantation fields next to wasteland, the rat population may fluctuate through a wide range from very low in some spots to very high in other places next to good rat cover. This condition will result in many empty pans in the high-population areas if a uniform amount of unpoisoned oats has been placed in all stations. It is necessary, then, that some provision be made to leave more grain in the more active stations. In experimental work, individual numbering of the stations and actually measuring and recording the consumption have enabled the operator to leave about the right amount of poisoned bait, but this is too slow for large-scale field operations. So a simple scheme of identifying the amounts of unpoisoned bait placed at each station was devised by R. L. Wold for Kaeleku Sugar Company.

The first requirement in starting this plan is to paint a large orange-colored arrow lengthwise on all station covers. The position of the arrow, in relation to

the trail as a base line, signifies the amount of bait that has been placed in that particular station.

By visualizing the face of a watch and remembering that the arrow at three o'clock is one cup, at six o'clock is two cups, at nine o'clock is three cups, and at twelve o'clock is four cups, there can be no difficulty in quickly reading the amount of unpoisoned oats that has been placed, no matter on which side of the trail the stations may be located (see Fig. 30).

These large colored arrows are also a great aid to visibility in finding the stations in densely covered places.
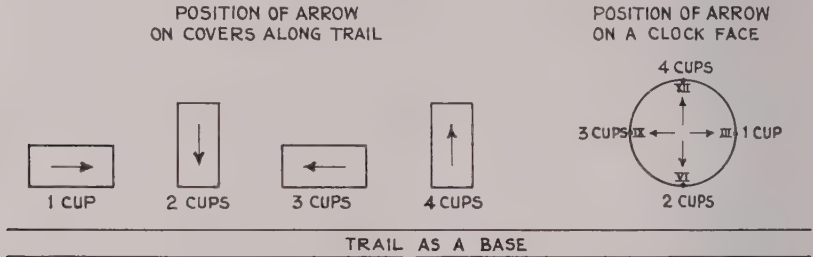
Fig. 30. The position of an arrow painted on the cover of the feeding station may be used to designate the amount of unpoisoned bait that has been placed in that station. The amount of bait is easily determined by visualizing the face of a clock.

Disposition of Residual Bait Material: Any unpoisoned oats that may be left in the pans at the time for poisoning should be returned to the warehouse and weighed. If these oats have not spoiled during their field exposure, they may be redried and used in the field a second time.

Any residue of poisoned grain should be returned to the warehouse and weighed before being finally discarded. It is generally conceded that poisoned grain should be used only once in the field. After careful baiting, it would be foolish to jeopardise the effectiveness of the subsequent application of poisoned bait by trying to make a small saving using questionable material. This would be particularly unwise when using zinc phosphide, which is known to deteriorate readily, and, in addition, is quite inexpensive. At Kaeleku Sugar Company some of these redried residual poisoned oats were disposed of by placing them as loose grain in protected pockets in stone piles in the hope that rats would consume at least a part before its final spoilage. Each plantation has worked out its own methods for final disposal of any unused poisoned baits.

Time Interval Between Visits: Reviewing briefly, the pans are placed in the field, filled with unpoisoned grain and covered on the first trip through the field. On the second trip, preferably four days later but perhaps only three days, the unpoisoned oats are renewed. The third visit should be made two or three days after the second trip at which time all unpoisoned oats are removed and poisoned oats are substituted. Following three or four days' exposure of poisoned oats, the stations may be picked up on the fourth visit and moved to a new area. This procedure requires a minimum of nine days for one poisoning cycle. Under special conditions it may be advisable to prolong the period of baiting with unpoisoned oats, but this will increase its consumption very materially. We have exceptional instances on

record where rats that had become bait shy from torpedo treatment required nine or ten days to become really active consumers at the feeding stations.

Strategy of Operations: In any military operation, in order to attack intelligently, we must have information about the enemy. Our enemy the rat is very reticent and secretive, and we are forced to spend a great amount of time and expend a large amount of energy to gather even small bits of information about what is going on in the "underground" rat world. It is essential that frequent inspections be made in all critical areas to discover if the rats are actively migrating into cane areas previously known to be clean. November and December seem to be the most likely time for this migration to occur. Traps may be used to advantage to determine the relative density of rat populations in special situations. The measuring of the consumption of unpoisoned and poisoned bait at index stations, which may be operated almost continuously in key locations, should also prove of great value in judging relative densities of rat populations. This information gathered from all available sources should be used in determining any changes or modifications in the standard routine of prebaiting the entire plantation at regular intervals. This information is also valuable as a guide in determining what modifications in the standard procedure might be beneficial in meeting special contingencies such as, for example, the use of direct poisoning without baiting as an emergency measure during an active migration from a harvest field or an active invasion from wastelands resulting from a severe drought or from a seasonal shortage of natural foods (see subject titled, "Conditions Necessary for Success").

Our experience with rats in cane fields has convinced us that control work must start very early in the life of the cane crop if it is to be done cheaply and efficiently. If this early work is done, we have not found it necessary to enter the center areas of a field after the crop has become big cane. Consequently the active fight can be confined to the perimeter of the field next to wasteland or other cover from which active infiltration may continue throughout the life of the crop. An active and successful campaign to protect a field having some edges exposed to wasteland, where rats are known to be abundant, should be planned something like this:

When a field of cane is being harvested, the area immediately around the field should be poisoned heavily by direct poisoning, either in covered pans or with torpedoes, to kill as many rats as possible as they are forced to seek new food supplies and adequate new cover. Then the area adjacent to this field should be baited and poisoned by lines of stations placed where rats which escaped from this field have secured permanent cover. From this time on, the edges and roads should be baited and poisoned every two to four months. Any stone piles or other permanent cover within the field should be included for treatment each time a prebaiting cycle is carried out. It is important that an open passageway be maintained between the cane and the wasteland throughout the crop so that the rat gang can get through to place their baits. If this baiting and poisoning of the borders have been carried out regularly from the very start of the crop, it should not be necessary to open trails in the center blocks of mature cane.

Kilauea Sugar Plantation Company has had excellent results using this plan and at very low cost per acre of cane protected. Kilauea concentrates all of its energy in rat-control work on the waste borders where infestation is *anticipated*. This

strategy also would apply at harvest time to the borders between an old field and a new field.

Once a field of big cane has become thoroughly rat infested through neglect earlier in the crop, it becomes necessary to place stations on trails spaced 200 to 300 feet apart throughout the area. This will be very costly and much rat damage will have occurred already.

The rat-control problem on a plantation located in favorable rat country like the region around Hana, Maui, has to be given special attention. Here it has been found to be impossible to control the rats by waiting until they are in the cane before attacking them. Instead the battle must be carried into the enemy country. So-called "buffer" trails have been cut in the forest 200–300 feet from the edges of cane fields and roughly parallel to the cane and along these trails semi-permanent feeding stations have been placed. The baiting and poisoning at these stations at frequent intervals has been very effective. The extremely heavy consumption of poisoned oats has indicated that large populations have been killed off before they had had an opportunity to migrate into the cane. Thorough poisoning of this protective barrier bordering the cane fields seems the most logical method of fighting the rats that constantly infiltrate into cane fields from outside waste areas. This protective barrier may be given greater strength in depth in special cases by opening still a second line of defense further into the dense vegetation. The continuous operation of key index stations on these buffer trails should give advance knowledge of the population movements which may menace the cane. A consistent and sharp rise all along the forest region should give advance notice of such destructive invasions as occurred at Kaeleku Sugar Company (see "The Control Problem at Hana"). At such a time the plantation should immediately marshal every available means including reserve supplies for the fight along the threatened borders.

Interval Between Poisoning Cycles: Rats migrate from near and even distant wastelands and reinfest carefully treated cane areas in a very short time. Under some abnormal conditions, where a narrow strip of cane or a small field is surrounded by wasteland, new rats migrating into the area in the short space of ten days will amount to as much as 30 per cent of the original population. This extreme condition would require that special attention be given to these areas beginning with very young cane. Gulches or waste areas adjoining harvested fields should receive treatment soon after harvest while the localized food supply is still low. Careful inspection for cane damage at strategic points will help to determine when it is necessary to repeat the baiting and poisoning process.

Except for these critical areas where special attention may be required, the whole plan of control for a plantation should be systematically carried out like any other essential operation, such as fertilizing or weed control, etc. This control work should be going on continuously throughout the year.

In general, rat-control operations should be repeated in a specific field often enough to keep the rat population so low that commercial cane damage does not occur. To accomplish this, the frequency of the rounds of baiting and poisoning will vary widely depending upon the rapidity of reinfestation in the particular area. Plantations on Kauai have obtained satisfactory control* by averaging from two to

*For a more detailed discussion see "Results of Prebaiting on Sugar Plantations."

four months between cycles for all lands under cane cultivation. This means, however, that areas adjacent to abundant rat cover may be treated as often as once in every four to six weeks at critical times, while other areas less subject to reinfestation may not be treated more than once in six months.

FIELD RECORDS:

It is now standard practice to weigh all baits going to and from the individual fields and to record them on simple individual field-record sheets. From these weights the net consumption of both the unpoisoned and the poisoned baits are calculated and reduced to a per acre basis for comparisons. A good example of a field-record blank is given in Fig. 31.

KAELEKU SUGAR COMPANY, LIMITED

FIELD RECORD OF PREBAITING
FOR RAT CONTROL

Field _____   Area _____ Ac.

Age _____ Mos.   Variety _____

No. of Stations _____   Grain _____

	Lbs. Unpoisoned	Date	Lbs. Poisoned	Date
Put Out				
Total				
Returned				
Consumed				

Ratio of Unpoisoned to Poisoned _____ :1

Ounces of Poisoned Bait Per Acre _____ oz.

Number of Dead Rats Seen _____

Remarks _____

_____

_____

_____

Fig. 31. Form for Field Record.

From this record of net poisoned oats consumed in a given area, a good estimate is obtained of the number of rats killed per acre. This measure of density may be used in comparing one field or area with another. The relative density of the rat population is the chief consideration when determining the length of interval to be allowed before another cycle of baiting and poisoning is expedient.

A monthly summary of rat-control work by field for a plantation should include at least the following information: Field No., Area, Age of Cane, Location of Stations (*re* edges, roads, level ditches), No. of Stations, Pounds of Unpoisoned Bait Taken, Pounds of Poisoned Bait Taken. Other items that may be included are: Pounds of Unpoisoned Bait Put Out With Per Cent Eaten, Pounds of Poisoned Bait Put Out With Per Cent Eaten. From these data, a very good idea of the exact status of rodent control can be obtained at any time.

PERSONNEL:

The success of the prebaited method of rat control is entirely dependent on the men in the field. They must be intelligent and absolutely reliable and able to work largely by themselves and on their own initiative. They should have a genuine interest and pride in doing their work precisely and well. Some sort of a premium or bonus system of pay for rat-control work serves to emphasize their responsibility and rewards their efficiency. As these men walk their routes through the fields they should seek to increase their efficiency in the placement of the stations by careful observations of the conditions of natural rat cover which lie immediately adjacent to the cane. While passing through or along good rat cover, they should automatically space the stations closer together, but on the other hand they should space the stations farther apart when crossing open spaces which offer little or no protection to rats. The exercise of judgment in placing the required amount of poisoned bait in the various stations, based on a knowledge of previous consumption of unpoisoned grain, will prevent waste, especially during rainy weather.

PRECAUTIONS FOR FIELD OPERATOR:

After many days of observation while tending the feeding stations in the field, the operator is too well aware of the filthy mess that the rats can make around active stations during wet weather. In certain extremely wet areas, infectious jaundice (Weil's disease, Spirochetal jaundice) may be present among the rats. It is possible for the operator to catch the disease by contact of rat urine with a cut or scratch on the hand. To guard against this possible infection, the hands and arms should be washed in creolin solution before and after the work, and rubber gloves should be worn while handling the stations. If care is exercised to always handle the pans with one particular hand, a glove on that hand alone is sufficient. It is also advisable to wear waterproof shoes or boots to prevent the possibility of infection by water through faulty footwear.

These precautions have been reasonably and sufficient observed by fieldmen in Hawaii so far, as no operator has been reported with any infection or illness which could be due to his association with the rat-control work.

Results of Prebaiting on Sugar Plantations:

EARLY RESULTS AT KILAUEA SUGAR PLANTATION COMPANY:

Kilauea's experience, in its efforts to stop the serious cane damage occurring in

its fields previous to 1937, is of interest here. Beginning in March 1936 the plantation placed dogs in the harvest field and kept a record of the catch of rats. During a 13-month period, from March 1936 to March 1937 inclusive, these dogs caught about 1,000 rats per month. Both dogs and traps were used in the harvest field during the year, from April 1937 to April 1938. For the first three months of this period, dogs and traps together accounted for over 4,000 rats per month. For the next six months after some prebaiting work was under way (June 1937) the average catch from dogs and traps still remained close to 3,000 a month. The actual catch of rats by traps and dogs at harvest time, from April to December 1937, amounted to a total of 24,294 rats and mice. The records of rats caught daily per 100 traps for this period showed a range from 15.6 to 32.2 with an average of 19.8. The use of dogs at harvest was discontinued in March 1938 after the full effect of the prebaiting program was evident. The number of rats caught had declined to such a low point that this practice was considered uneconomical. However, the trapping was continued from May to October 1938. This method averaged about 600 rats per month, and was finally discontinued due to the rapid decline in catch. By that time the trapping index had declined to a record low of five rats per 100 traps indicating that excellent control was at least within reach. From that time until the present, Kilauea has relied entirely on the prebaiting method of rat control. This has further reduced the rat population to such an extent that commercial cane damage has been eliminated unless an area has been neglected for several months. Judging from the study of the trapping records at Kauai Variety Station, the present rat-trapping index at Kilauea must be below "2" (23, pp. 73–82).

As an example of the comparative density of rat populations before and after prebaiting, the detailed data from two successive harvests from a specific field at Kilauea are of interest. The 1937 crop from a 70-acre field (Field 4) of Badila cane was harvested June-July 1937 before prebaiting was started. Observations showed that more than 25 per cent of the cane had been injured by rats. The 1938 crop from the same field was protected from rat damage by prebaiting at intervals during its growth, until it was harvested in August 1938. The tabulations below show the contrast in the rat population of the field under the two sets of conditions:

COMPARATIVE RAT CATCHES DURING TWO CROPS IN FIELD 4, KILAUEA

Before Prebaiting Program
1937 Crop Harvested June-July 1937

| Rodents caught | | Trap days | Rats per 100 traps | Rats caught by dogs |
Rats	Mice			
934	173	3237	28.9	1050
(13.3 rats per acre)				(15 rats per acre)

Under Prebaiting Program
1938 Crop Harvested August 1938

| Rodents caught | | Trap days | Rats per 100 traps | Rats caught by dogs |
Rats	Mice			
14	27	917	1.5	None

The following tabulation shows the amount of poisoned oats eaten by rats during the growth of the 1938 crop. This consumption of poisoned oats resulted in the decimated rat population at harvest, indicated by the low index of 1.5 rats per 100 traps per day.

Date of poisoning	No. of stations	Lbs. of poisoned oats eaten	Location notes
July 1937	114	9.5	Edges after harvest
Dec. 1937	108	6.5	Edges
Mar. 1938	72	4.0	Edges
May 1938	70	4.5	Roads
July 1938	66	3.0	Edges and drain
	430	27.5	

RAT TRAPPING RECORDS SHOW EFFECTIVENESS OF CONTROL METHODS:

In a recent article (23, pp. 73–82), the writer presented detailed trapping records covering a period of five years as a basis for evaluating the efficiency of the pre-baited feeding-station method of rat control. These data, gathered from our Kauai Variety Station located in the center of a large area of good cane land of Lihue Plantation, showed the high degree of efficiency that can be attained by systematic and continuous rat-control measures. The main features of this article are summarized as follows:

(1) Before systematic prebaiting was inaugurated, the field-rat population
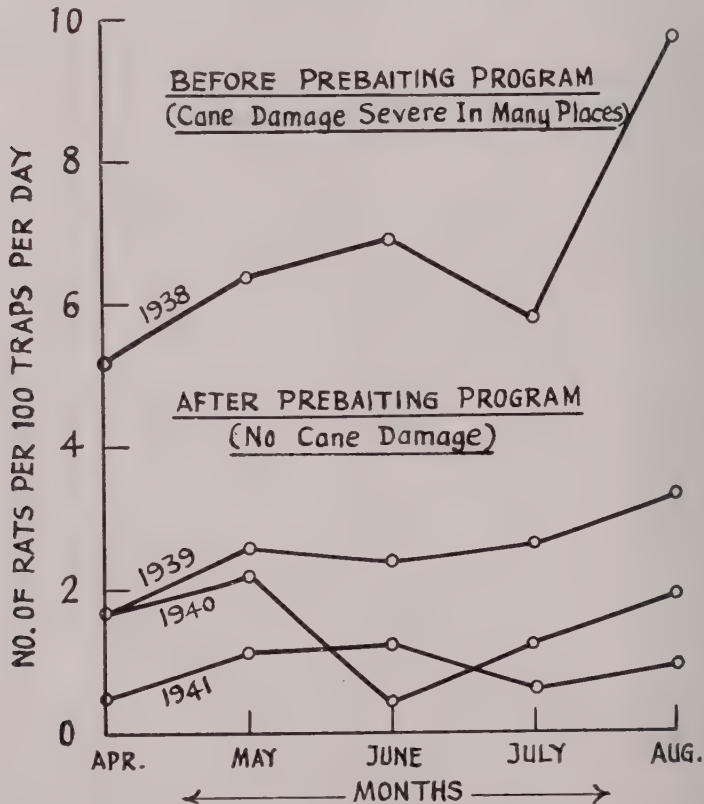
Fig. 32. Graphic presentation of the average number of rats caught per 100 traps per day at the Kauai Variety Station, comparing the period April to August 1938, with that of the corresponding months of the years 1939, 1940, and 1941 after a systematic prebaiting program has been inaugurated. After Doty (23).

yielded an average catch of 6.8 rats per 100 traps daily for the months from April to August 1938.

(2) During the corresponding months of the following years (1939–1943 inclusive) a very satisfactory reduction in the rat population was maintained by the prebaiting system of control. All commercial cane damage by rats ceased somewhere between the extremes shown in Fig. 32. The average number of rats caught from April to August before prebaiting, compared with those caught after prebaiting was established, is shown in the following tabulation:

	Year	Average number of rats caught per 100-trap days for the months of April to August
Before prebaiting	1938	6.8
After prebaiting	1939	2.52
	1940	1.48
	1941	0.86
	1942	0.80
	1943	0.94

(3) The yearly averages of the rats caught per 100-trap days since prebaiting was started are given:

Year	Rats per 100-trap days
1938 (September to December only)........	4.82
1939	2.79
1940	1.70
1941	1.48
1942	1.42
1943	1.55
1944 (January only)......................	1.30
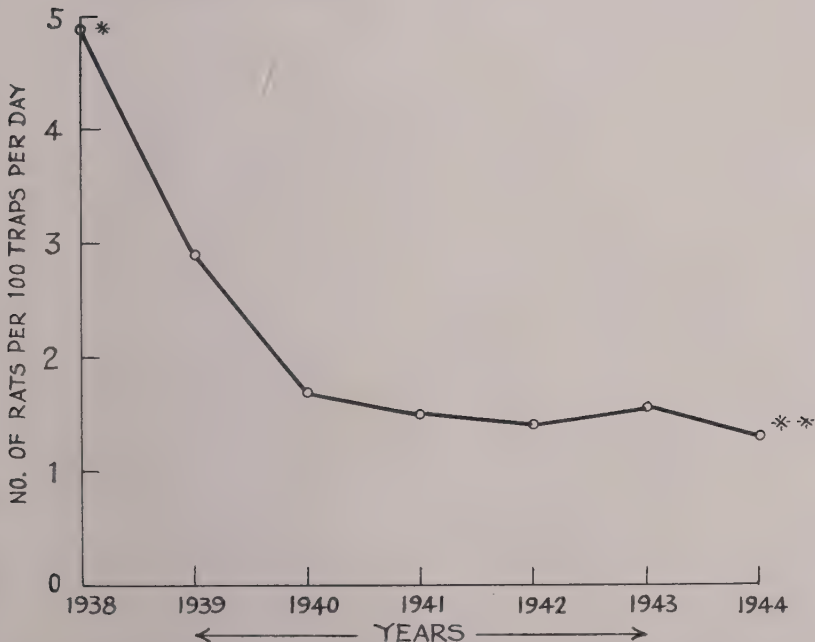
Fig. 33. Average number of rats caught per 100 traps per day under prebaiting control by The Lihue Plantation Company (averages by years for the period from August 27, 1938, to January 25, 1944). After Doty (23). * September to December inclusive. ** January only.

These results are shown graphically in Fig. 33 and indicate a marked reduction in the rat population index from 1938 to 1939 and 1940, followed by only slight fluctuations from 1940 to date. Apparently a low point in the rat population has been reached where reinfestation prevents any appreciable reduction by the present control methods. However, an almost total absence of rat-eaten cane stalks is evidence that the present schedule of baiting and poisoning is giving very satisfactory control.

(4) A study of the change in rat population with elapsed time following baiting and poisoning periods shows that no significant or damaging increase took place during the interval (averaging 3½ months) between prebaiting cycles. Even the usual seasonal variation in migration to cane land from outside areas was greater than this increase due to the length of time between poisonings.

CONSUMPTION RECORDS:

As it is now six years since the first experimental work in field baiting and poisoning was reported, a review of the present status of the rat control work is in order. At this date, all plantations (with one exception) which have seriously taken up prebaiting work have attained a thoroughly satisfactory control, resulting in no commercial cane damage as long as the program is executed properly. The one exception—the cane area at Hana, Maui, where all natural conditions favorable for rats prevail—will be discussed separately.

Four plantations,* which have kept complete records of their field work for from four to six years, have made these data available for study. From an analysis of these data, we can take stock of our present status and perhaps discover trends that will enable us to plot our course for the future.

A summary of these records, showing the yearly average amount of poisoned oats consumed by rats in grams per acre per application, is given in Table III. To visualize this summary in more practical terms, a theoretical minimum number of rats killed per acre by this poisoned bait is shown in the second half of the table. These estimates were calculated on the basis of five grams of poisoned bait consumed per rat. The average-sized rat is calculated to weigh 150 grams or ⅓ pound.

TABLE III

YEARLY AVERAGE AMOUNT OF POISONED OATS CONSUMED BY RATS PER ACRE PER APPLICATION IN GRAMS DURING 1937–1943, AND AN ESTIMATE OF THE MINIMUM NUMBER OF RATS KILLED

Plantation	Consumption per acre per application						
	1937	1938	1939	1940	1941	1942	1943
Kilauea	51.4*	43.2	46.3	46.1	45.5	41.4	47.4
Lihue	....	44.0	39.5	36.5	32.2	31.3	36.7
Grove Farm	....	....	39.5	41.3	26.8	19.5	24.2
Kaeleku	....	....	153.8*	187.8	171.5	163.3	162.8
Plantation	Estimated minimum number of average-sized rats killed per acre per application						
	1937	1938	1939	1940	1941	1942	1943
Kilauea	10.2*	8.6	9.2	9.2	9.1	8.2	9.5
Lihue	....	8.8	8.0	7.3	6.4	6.2	7.3
Grove Farm	....	....	8.0	8.2	5.4	3.9	4.8
Kaeleku	....	....	30.8*	37.6	34.3	32.7	32.6

*Record for 7 months only.

*Kilauea, Grove Farm, Lihue, and Kaeleku have kindly supplied us with their unpoisoned and poisoned bait consumption records.

Since the time interval between cycles directly influences the number of rats available for poisoning at any one time, it is necessary to determine the number of cycles per year before making any comparisons. Table IV gives the average number of periods of baiting and poisoning per year, and Table V, a consolidation of Tables III and IV, gives the average number of grams of poisoned oats consumed per acre for an entire year with the probable number of rats killed. These data are presented graphically in Fig. 34.
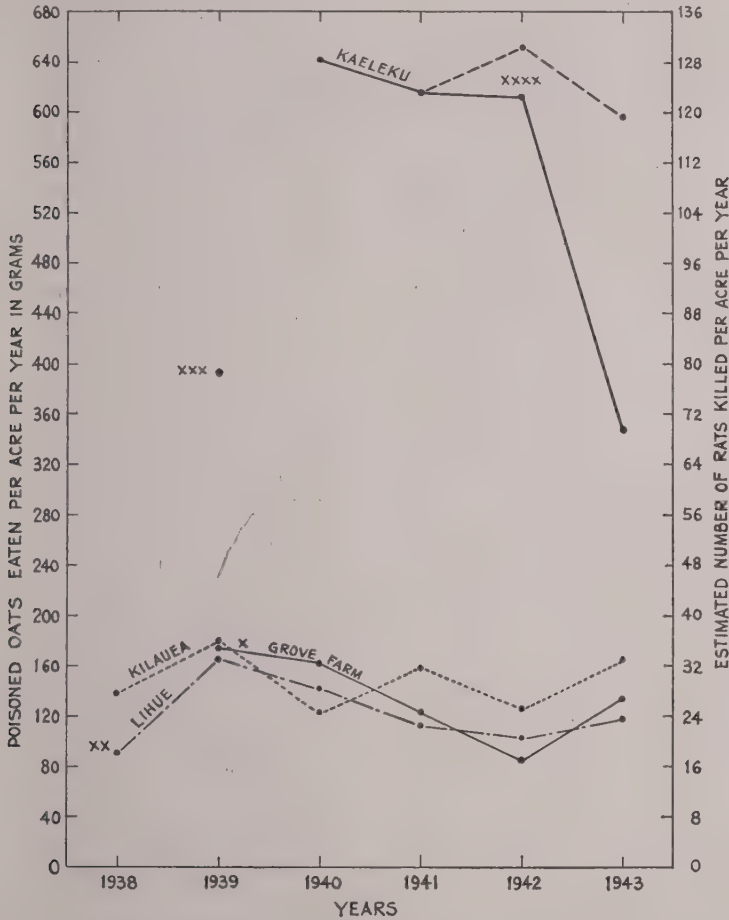
Fig. 34. Graphic presentation of the average amount in grams of poisoned oats consumed by rats per acre per year, and an estimate of the minimum number of rats killed per acre by this poisoning each year (from Table V).

x Incomplete. A seven-month record adjusted to a twelve-month basis.

xx Work was hampered by shortage of equipment at the start.

xxx Incomplete. A seven-month record at Kaeleku Sugar Company adjusted to a twelve-month basis.

xxxx Note that the consumption at Kaeleku for 1942 and 1943 has been segregated to show the consumption of poisoned oats at all stations in cane and on the edge of cane (solid line) compared with the total consumption of all stations (broken line) which includes those stations operated on the forest trails.

TABLE IV

AVERAGE NUMBER OF PREBAITING CYCLES MADE PER YEAR

Plantation	1937	1938	1939	1940	1941	1942	1943
Kilauea	1.2*	3.2	3.8	2.6	3.5	3.1	3.5
Lihue	....	2.0	4.2	3.9	3.6	3.3	3.2
Grove Farm	....	....	2.6*	4.0	4.6	4.3	5.5
Kaeleku	....	....	1.5*	3.4	3.6	4.0	3.7

*First trials; insufficient equipment; 7-month record only.

TABLE V

YEARLY AVERAGE TOTAL AMOUNT OF POISONED OATS CONSUMED BY RATS PER ACRE PER YEAR IN GRAMS, AND AN ESTIMATE OF THE MINIMUM NUMBER OF RATS KILLED PER ACRE EACH YEAR

Plantation	Consumption per acre					
	1938	1939	1940	1941	1942	1943
Kilauea	139.3	177.4	120.7	158.8	126.1	164.2
Lihue	89.8*	165.6	142.0	115.7	102.1	118.8
Grove Farm	....	174.3†	162.8	122.5	84.4	133.8
Kaeleku	....	394.6†	643.2	618.7	655.5	596.5
(Stations on forest trail only................................					39.6	248.4)
(Stations in and on edge of cane only........................					615.9	348.1)

Plantation	Estimated minimum number of rats killed per acre					
	1938	1939	1940	1941	1942	1943
Kilauea	28+	36+	24+	32+	25+	33+
Lihue	18+*	33+	28+	23+	20+	24+
Grove Farm	....	35+†	33+	25+	17+	27+
Kaeleku	....	79+†	129+	124+	131+	119+
(Stations on forest trail only...................................					8+	49+)
(Stations in and on edge of cane only...........................					123+	70+)

*Work started first of year but equipment had to be built up.
†Seven-month record adjusted to a 12-month basis for comparison—equipment was inadequate to cover area.

Grove Farm leads the group since 1940, with the highest number of cycles (5.5) in 1943 but by far the lowest poison consumption and smallest number of rats killed for each cycle. On a yearly basis Grove Farm and Lihue have killed almost the same number of rats per acre although the latter plantation made only 3.2 cycles during 1943. On the average, Kilauea has killed a few more rats per acre in a year than either Grove Farm or Lihue and accomplished this with 3.5 cycles in a year. Fig. 34 clearly shows that Kilauea, Grove Farm and Lihue, all on windward Kauai, have streamlined rat control to a maintenance basis. The killing of 17 to 35 average-sized rats per acre each year by poisoning just balances the reinfestation occurring from adjacent waste areas and any natural increase from those actually missed by the poisoning periods. Field and mill observations have amply confirmed that when control measures have been maintained efficiently, *commercial cane damage by rats has been entirely eliminated*. However, any curtailment in the control measures in any particular field or region will result in an immediate upset of the apparent balance between the control measures on one hand, and the continuous reinfestation from waste areas on the other. An immediate upward surge of the rat population in this particular area will inevitably result, in a very short time, in serious rat damage to the cane.

THE CONTROL PROBLEM AT HANA:

The Hana district on Maui has always had a serious rat problem ever since sugar cane growing on a commercial scale was attempted. Prebaiting was started on a field-scale basis in the summer of 1939. Each year more labor and equipment have been devoted to this work, yet during each winter season there has always been an inadequate supply of stations to fight the vast hordes of young rats which migrate to the cane fields from all wasteland borders. Serious cane damage has always resulted before those new migrants could be killed by poisoning.

The seriousness of the problem during this period can be realized by noting the extremely heavy consumption of poisoned bait at Kaeleku Sugar Company for the months of December, January and February (illustrated in Fig. 35). Also a glance at Tables III, V and VIII and Figs. 34 and 35 shows the magnitude of the rat-control problem of Hana compared with that of Grove Farm, Lihue or Kilauea.

Kaeleku covered its cane area 3.7 times in 1943 (Table IV), exceeding all other plantations reporting except Grove Farm (5.5 times), yet the consumption figures for each cycle (Table III) and for the year (Table V) indicate that there are *5 times as many rats* being killed per acre each year. For the years 1940 to 1943 an average of 628.5 grams (1.4 pounds) of poisoned oats was consumed by rats per acre of cane accounting for the death of a minimum of 126 average-sized rats.

Exceptionally high rat populations may occur in small areas of cane more or less surrounded by wasteland. A ten-acre field of 31–1389 (Field 4A) is a typical example. For a *single period of poisoning* during May 1941, the consumption of oats *amounted to 51.2 ounces* (3.2 pounds) per acre, *representing an estimated rat population of 275 to 300 rats killed for each acre of cane.* During the same month, in another field of 54 acres of 31–1389 and Yellow Caledonia, rats consumed 120 pounds of poisoned oats or 35.6 ounces (2.22 pounds) per acre including some consumption along an adjacent forest trail. In this second example a probable 200 rats were killed per acre during a single period of baiting and poisoning. While these examples are exceptional instances, the fact that such cases do occur leaves no doubt as to the seriousness of the problem.

From the fact that this number of rats could be killed, it is apparent that the normal migration into cane during the interval (2½ to 3 months) between cycles would represent such large numbers of rats that tremendous damage would be done to the cane in a very short time, just previous to the next baiting and poisoning periods. We have ample proof of the high efficiency of each baiting and poisoning period in cane fields but in many cases the cane had been seriously damaged before control was effected. The most obvious remedy, that of decreasing the interval between cycles to two months or less, as has been done at Grove Farm, would undoubtedly give some relief, but this has not always been possible at Hana due to labor and equipment shortages during the war. Also, along the edges of good rat cover, the distances between stations should be reduced to 50 or 60 feet to intercept better the rat traffic from the forest into the cane field.

In spite of the limited labor and equipment available, Kaeleku is now making substantial progress toward a solution of the rat problem by adopting a policy of not only fighting the rats in the cane and on the field borders, as has been done so successfully on Kauai, but of pushing the attack into the forest waste and killing as many of the rats as possible that live and feed within 500 feet of the cane field
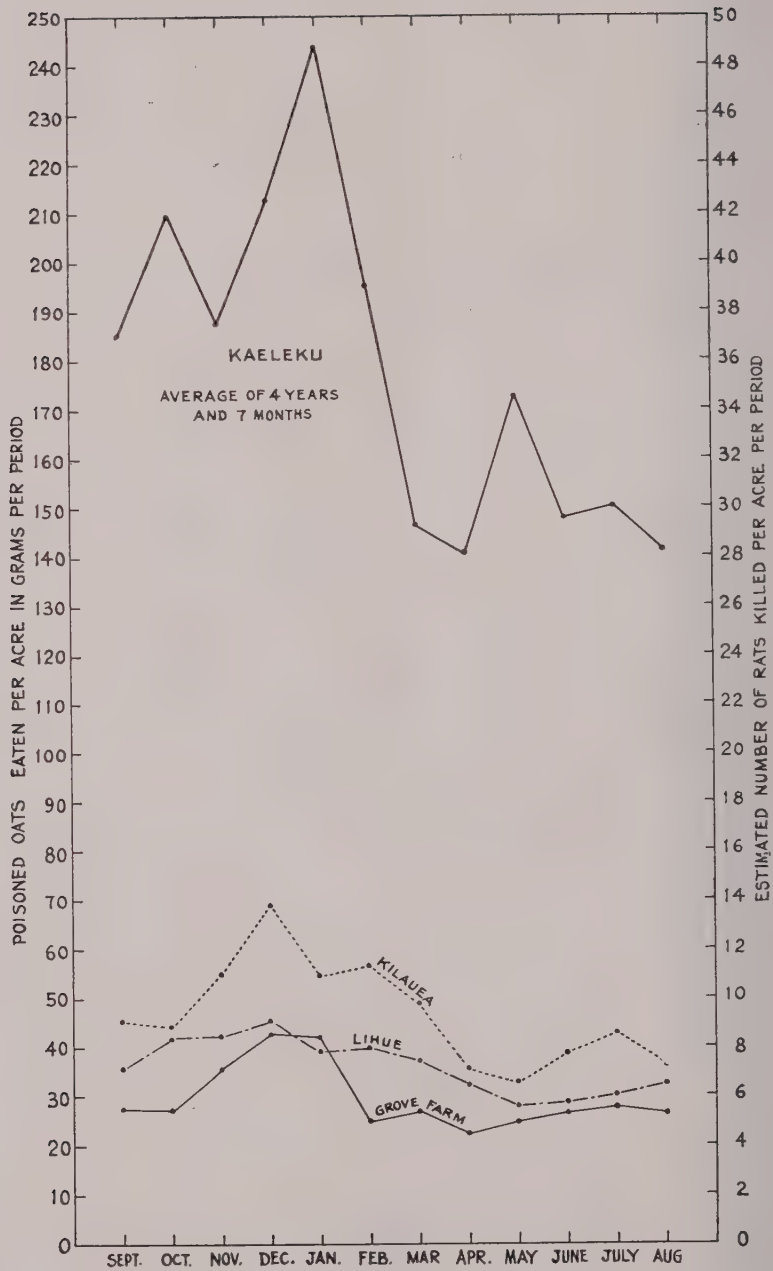
Fig. 35. Graphic presentation of the average amount of poisoned oats eaten per acre per period, four- to six-year average by months (from Table VIII). Estimated number of rats killed per acre per period is also shown.

border. Certain fields located next to favored cover are subjected to devastating rat damage each winter season (December, January, February) when rat migration is at its peak. The plantation is concentrating its effort in these potentially danger-ous areas by operating large numbers of permanent and semi-permanent feeding sta-tions along "buffer trails" which have been cut through the forest or wasteland 200 to 300 feet from, and running roughly parallel to, these critical cane field borders.

This procedure is not only sound strategy but also has proved to be good econo-mics. A segregation of poisoned bait consumed during 1943 in stations *in the cane* or on the edge compared with the poisoned bait consumed in the stations *located in the forest* is convincing.

TABLE VI

RELATIVE CONSUMPTION OF POISONED OATS AT FEEDING STATIONS
LOCATED IN THE CANE FIELD AND FOREST

Location	Total stations operated for entire year	Total consumption (lbs.)	Average consumption per station per round	
			Lbs.	Grams
In cane field	47,830	2512.5	.0525	23.8
On forest trail	17,996	1792.5	.0996	45.2
Total for all areas..............	65,826	4305.0	.0654	29.66

These data show that approximately twice as much poisoned bait was consumed at each station on a buffer trail in the forest as was consumed at any station in or on the edge of cane. The average consumption was 45.2 grams of poisoned oats per station per period in the wasteland compared with 23.8 grams consumed per station in the cane. Not only was each station in the forest twice as efficient in killing rats, but also *most of these rats had not yet eaten sugar cane.*

These data are considered very significant and strongly suggest that control ef-forts should be directed more than ever toward *fighting the rats on and beyond the cane field borders.* We are also convinced from this evidence that substantial prog-ress can be made by increasing the number of stations along the borders and in the wasteland as well as by decreasing the interval between cycles. The best use of additional stations can be made by increasing the depth of defense by placing and baiting a second line of feeding stations on trails laid out some 150 to 200 feet fur-ther into the forest beyond the first line of forest-trail stations. With many of these stations almost constantly in use it should be easier to detect pronounced increases in consumption and thus have advance warning when a general rat invasion is immi-nent. With increased baiting and poisoning in this "barrier strip," where it can be performed more economically, the amount of prebaiting in the cane fields can event-ually be correspondingly reduced.

During 1943 this method of stepping up the attack in the forest gave the most encouraging results of any year since prebaiting work was seriously attempted at Kaeleku. The number of rats killed in or on the edge of cane during 1943, as measured by the consumption records (Table V), shows a very abrupt decline from the 1942 figures (estimated at 123 for 1942 compared with 70 rats killed per acre per year for 1943, Fig. 34). This is the first improvement since the detailed records of rat control have been kept. While it is true that when the number of rats killed in the forest is added to the number killed in the cane, we have a total figure (119) almost as great as for any of the previous years, *there is this significant difference:*

the rats in the forest were killed before they had damaged the cane. This fact must be entirely *responsible* for the *encouraging reports* received from fieldmen that during the winter of 1943–1944 there had been much less cane damage by rats than for many preceding seasons. It is apparent that the extra effort by the plantation rat-control gang, mainly in the forest, during November, December and January has lowered the peak of cane damage, which normally occurs at this time. *Adequate commercial control at Kaeleku is actually within sight.*

NUMBER OF FEEDING STATIONS PER ACRE:

The number of feeding stations per acre per period required to attain adequate control depends on several factors, but chiefly on the relative density of the rat population. As has been stated frequently before, the stations should not be equally spaced over all kinds of terrain and cover but concentrated (50–60 feet apart) in or near heavy rat harborage, with relatively few stations placed in open areas (100–125 feet apart) where little or no rat cover is available. Records of actual experience from plantations showing the number of stations per acre of protected* cane for each prebaiting cycle averaged over all kinds of terrain and with varying amounts of cover are given in the following table. These data are presented graphically in Fig. 36.

TABLE VII

AVERAGE NUMBER OF STATIONS PLACED PER PREBAITING CYCLE
PER ACRE BY YEARS

Plantation	1937	1938	1939	1940	1941	1942	1943
Kilauea	1.6	1.7	1.7	1.8	1.8	2.0	2.1
Lihue	...	2.4	2.4	2.5	2.7	2.7	2.9
Grove Farm	...	...	1.7	1.5	1.5	1.6	1.5
Kaeleku	...	...	1.6	2.3	3.7	4.3*	5.5†

*.15 in forest; 4.15 in cane.   †1.5 in forest; 4.0 in cane.

It is very significant that Kaeleku Sugar Company, in its efforts to secure adequate rat control, has increased the average number of stations used per acre of cane protected per cycle of prebaiting with each succeeding year up to 5.5 for 1943. However, only four stations per acre per cycle were actually in or on the edge of cane fields. The remainder (1.5 stations) were on trails in the forest where large numbers of rats were being killed before they had actually eaten any cane. On the other hand the plantations on Kauai, which have already attained complete commercial control, continued to handle a very low number of stations per acre (1.5 to 2.9).

According to Table V Kaeleku has approximately 5 times as many rats per acre as any plantation on Kauai, consequently their 5.5 station per acre for 1943 is still far below the requirements for adequate control. However, adequate control is soon to be attained if the reports for January and February 1944 are any criterion. The number of stations in operation per acre of protected cane for January was 7.7 (3.1 in forest) and for February was 7.2 (2.7 in forest). This means that larger numbers of stations were in operation on the edge of the forest than at any previous

*Cane that is relatively secure from rat damage, due to the presence of poisoned bait properly placed in feeding stations so that the rats are poisoned before they can damage the cane, is said to be "protected."

time. This policy at Kaeleku of expanding the rat-control work to meet the magnitude of the problem is beginning to give very encouraging results.

SEASONAL FLUCTUATIONS IN RAT POPULATIONS:

It is generally recognized among fieldmen that cane damage by rats is more severe during the winter months than at any other period of the year. To gather information on this point, the amount of poisoned bait consumed under prebaiting was assumed to be a relative measure of the population present. The records of the prebaiting work carried on by four plantations since 1938 were summarized. The amount of poisoned oats consumed per acre per period by months was averaged for six years and is presented in Table VIII. These data are plotted in Fig. 35.

The most noteworthy fact brought out in this table and graph is the extremely heavy consumption of poisoned bait per acre per period at Kaeleku Sugar Company during the months of December, January and February, while from March to August the consumption was only about half as much. Even this latter amount was very high compared with the consumption of poisoned bait on the Kauai plantations. However, the poisoned-bait consumption for Kilauea, Lihue and Grove Farm, while roughly only one-fifth as much as at Kaeleku, followed the same general pattern, being high in December, January and February and low from March to August. These figures on poisoned-bait consumption, indicating a definite seasonal fluctua-
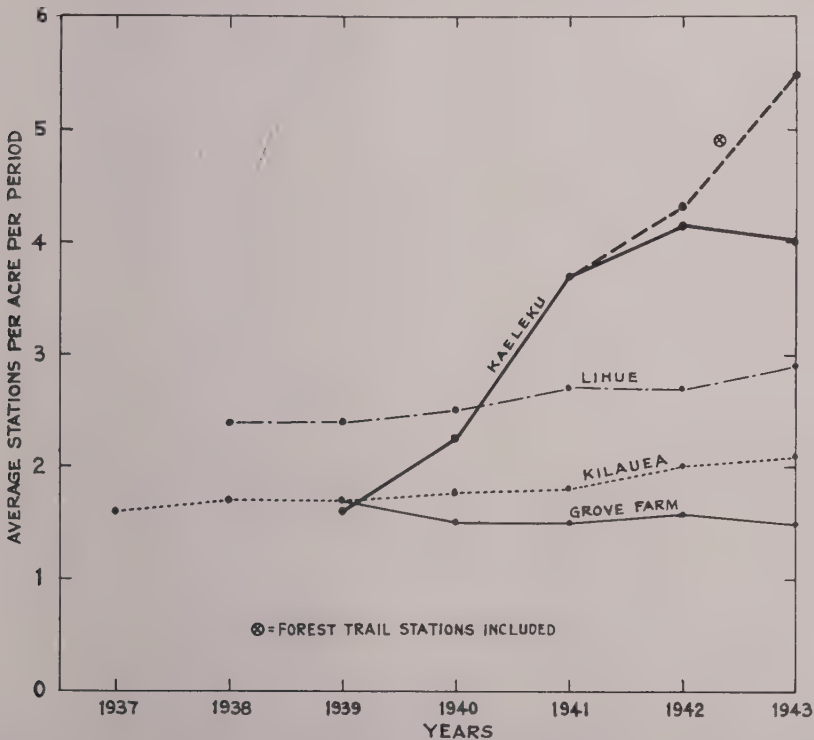
Fig. 36. Graphic presentation of the average number of feeding stations per acre of protected cane per period by years (from Table VII).

tion in the rat population, corroborate results obtained from continuous trapping operations conducted at the Kauai Variety Station and discussed by the writer in a recent paper (23, pp. 78–79). The trapping records at the Kauai Variety Station show a period of ever-increasing rat migration into the cane from August or September to January inclusive which reached a peak during January of each year and then declined again to a low level which continued from April to August (see Fig. 37). The total range of this seasonal fluctuation in rat population as measured by rats caught per 100 traps per day was from a low of one rat per 100 traps per day for April to a high of three in January.

TABLE VIII

AVERAGE AMOUNT BY MONTHS OF POISONED OATS CONSUMED IN GRAMS
BY RATS PER ACRE PER PERIOD (1938–1944)

Plantation	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Kilauea	54.6	56.3	48.5	35.9	32.5	39.0	43.0	36.0
Lihue	39.2	40.0	37.2	32.7	28.4	28.7	30.2	32.1
Grove Farm ...	39.8	24.7	26.5	22.4	24.5	25.2	27.4	26.1
Kaeleku	243.8	195.1	146.1	140.7	172.5	147.6	150.4	141.4

Plantation	Sept.	Oct.	Nov.	Dec.	True average	Notes
Kilauea	45.4	43.9	54.8	69.1	46.6	(Avgs. for 6 yrs. and 5 mos.)
Lihue	36.8	41.8	42.0	45.0	36.7	(Avgs. for 6 yrs.)
Grove Farm	27.6	27.1	35.4	42.9	29.4	(Avgs. for 4 yrs. and 9 mos.)
Kaeleku	185.3	210.9	187.3	212.8	178.6	(Avgs. for 4 yrs. and 10 mos.)

We do not have enough data to attempt to compare the results obtained from trapping at the Kauai Variety Station with the figures for consumption of poisoned bait obtained over the entire plantation (Lihue), but it is extremely interesting to note that the low average consumption per acre per period for five years at Lihue was 28.4 grams for May and that the high was 45.0 grams for December. We must, however, admit the similarity in trend for results obtained from these two different methods of measuring rat populations.
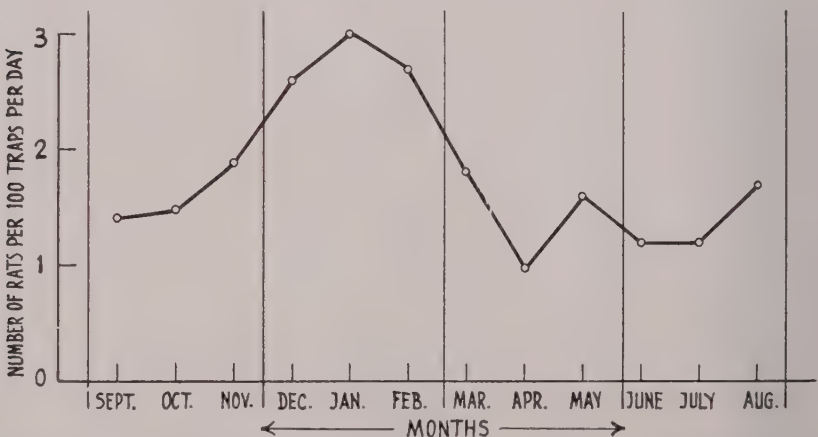
Fig. 37. Average number of rats caught per 100 traps per day at the Kauai Variety Station under prebaiting control by The Lihue Plantation Company. Five-year average by months, 1939–1943. After Doty (23).

Experimental Studies in Rat Control:

METHODS:

In a study of field treatments on rat control it is necessary to have some method for measuring and comparing visible and tangible evidence. Under the prebaited feeding-station method, wherein we aim at having a surplus* of food present in the feeding stations during the period of study, an index of the population can be obtained by measuring the amount of unpoisoned oats eaten per night, especially the last night before poisoning, followed by a measurement of the poisoned oats consumed. This method offers a means of comparing the density of the population per acre of one area with another. The approximate effectiveness of a specific poison treatment expressed in per cent of the original population may be determined by measuring the consumption of unpoisoned oats during the same length of time interval immediately before and after the treatment. In cases where limited areas under study are adjacent to heavily populated untreated areas, the amount of migration into the treated area occurring during the period of study will be a disturbing variable. This factor can be evaluated by repeating the baiting and poisoning campaign to obtain a consumption figure for that final period.

In cage tests we recorded many exact measurements of consumption of both unpoisoned and poisoned oats in relation to the weight of the rat; but we have no positive means of adjusting accurately this ratio of a specific food consumed to the weight of a rat, so that it will apply in the field where other food may be plentiful. However, field measurements on a percentage basis do offer a valuable means of comparing the consumption of oats before and after a specific treatment, without trying to convert this result to actual number or pounds of rats. This idea has been followed in reporting the results of our field tests in this paper.

REVIEW OF THE ORIGINAL FIELD EXPERIMENTS IN PREBAITING:

Two extensive tests with prebaited feeding stations were conducted at Kilauea Sugar Plantation Company during the spring of 1937 and have been previously reported (22, pp. 63–68). These studies are reviewed here because they furnish an excellent field demonstration of prebaiting, as they were made in big cane and on a much larger scale than had been possible at any time previous. For the purpose of determining just what was happening in each test both were visited oftener and were continued for a longer time than would be necessary for a practical control.

Kilauea Experiment No. 1: The area chosen (Field 20) for this first experiment contained 45 acres of POJ 2878 and 34 acres of Badila, all one-year-old cane. Two hundred and fifty-five feeding stations of the standard type previously described were placed in this field on April 10, 1937. Unpoisoned and poisoned (thallium—1–250) oats were used in these stations as follows: (1) six days with unpoisoned oats; (2) six days with poisoned oats; (3) four days with unpoisoned oats; and (4) two days with poisoned oats. Coconut oil was used with both un-

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*This is the distinguishing point between our method of prebaiting and the well-known system of prebaiting with small amounts of an acceptable food for one or more days followed by adding poison to the same kind of food. Chitty (11) of Oxford University has stated that, "We have termed this system 'token' as distinct from 'surplus' prebaiting which, so far as is known, has only been used before in Hawaii."

poisoned and poisoned oats, approximately one quart to fifteen pounds of oats. (Later work has shown three to four quarts per 100 pounds to be sufficient.)

The detailed consumption by stations was carefully tabulated and summarized and the data are presented in Table IX. Three stations have been omitted in the tabulated data because records were lost on the second day of poisoning due to a five-inch rain which flooded the three stations.

TABLE IX

SUMMARY OF THE DATA OBTAINED FROM KILAUEA EXPERIMENT NO. 1

	Unpoisoned oats			Poisoned oats		Unpoisoned oats	Poisoned oats
Interval (days)	2	2	2	3	3	4	2
No. of stations showing no acceptance	168	9	0	9	233	218	246
No. of stations showing some acceptance	84	243	252	243	19	34	6
Total oats eaten (grams)..	2302	20390	26292	10950	101	504	41
Avg. acceptance per active station between measurements (grams)	27.4	83.9	104.3	42.9	5.2	14.8	6.8
Avg. daily acceptance per active station (grams)...	13.6	42.0	52.2	......	....	3.4	.....
Total oats eaten (pounds).	....	....	108	......	24.34	1.1	0.09
Total oats eaten during each interval (pounds)	5.1	44.9	57.9	24.12	.22	1.1	0.09
Avg. daily consumption (pounds)—252 stations ..	2.5	22.5	29.0	......	....	.27	.....
Ratio: poisoned to unpoisoned oats				1:4.4			

After the first two days exposure of unpoisoned grain, only one-third of the stations showed any activity with an average of only 13.6 grams of oats consumed per active station. Many tracks of mice were noted, but few evidences of rats. Even when the stations were deliberately placed on a fresh rat trail coming out of the gulch cover, little or no oats were eaten. In four days, however, all but nine stations out of the total of 255 had become active with an average daily consumption of 42 grams for each. Those stations located on rat trails from the gulch were now among the most active stations in the field. After two more days exposure (total six days) all stations had become active with an average daily acceptance of 52 grams per station. In a few cases rats dug tunnels under emptied pans in an attempt to locate additional food. In one case a fresh hole had been dug next to the station, indicating a desire to live close to the source of the new food. When poisoned oats were applied, nine stations became inactive leaving 243 with an average consumption of 43 grams, a decline of 9 grams or 17 per cent from the best day of unpoisoned acceptance. This decline in consumption on the night of substituting the poisoned grain has always occurred and varies only in degree. The cause is not known but some of the possibilities will be discussed later under "Acceptance of Poisoned Oats." Although the figure obtained covered three nights of poisoning, most of the poisoned oats (87 to 90 per cent) were consumed on the first night, with a rapid decrease each succeeding night, so the total only can be shown. Poisoned rats cannot return to eat on the following day.

For experimental purposes the poisoned bait was left in the field a second period of three days after the first record had been taken. Only 19 stations or 7¾ per

cent showed any further disturbance of the poisoned oats with only a total measured amount eaten of .22 pound or $\frac{9}{10}$ of one per cent of the amount eaten in the first three days of poisoning. It therefore seems questionable whether it is worthwhile to leave the poisoned bait in the field the extra three days. It is quite probable that most or all of this small consumption occurred on the fourth night immediately following the first record. Later work has amply demonstrated that three nights of exposure of poisoned bait following a baiting period is sufficient for good field practice.

The average daily consumption of rolled oats in pounds (Table IX) for the entire test is shown graphically in Fig. 38.

Experiment 1
KILAUEA S. P. CO. FIELD 20
Graph Showing Average Daily Consumption In Total Pounds Of Rolled Oats From 252 Feeding Stations
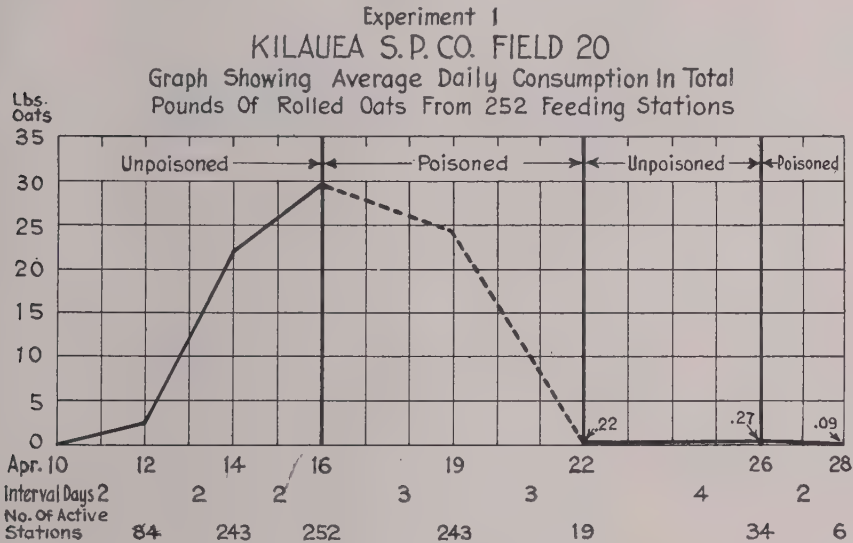
Fig. 38. From Table IX. After Doty (22).

Distribution of Rat Population: The detailed data, station by station, have been plotted and are shown in Fig. 39. A large dot was placed on this map for each 1/40 pound or 11.3 grams of poisoned oats consumed. This amount is a lethal dose for 3.4 pounds of rats and could account for three or four average-sized rats and allow a margin for some of them to eat more than the minimum lethal dose. By this method a graphic picture is presented of the distribution of the rats in the field in relation to natural cover occurring around the field.

The areas along the clean open pasture and young cane harbored comparatively few rats. An extremely heavy infestation occurred along the gulches where the natural cover of panicum grass, honohono, morning glory and lantana make the area almost impenetrable. Along this area there were many distinct and clear-cut rat trails through the grass from the gulch directly into the cane. The greatest damage to cane invariably occurred at the heads of the small gullies or field drains.

A Study of Distance Between Stations: Four level ditches and a 350-foot strip along the gulch were purposely omitted in the first poisoning. These areas are blank on the map in Fig. 39. On April 22, 32 new stations were placed in the four level ditches and the 350-foot strip along the gulch which had been omitted in the original

placement. These were baited with unpoisoned oats. On April 26 the 32 stations were baited with poisoned oats. Only four days of unpoisoned bait instead of the usual six days were allowed in this instance in order to save time, as very little activity was evident in these areas. One station in a low spot was lost by flooding. Two days later (April 28) the amount of consumption was measured and recorded, and is summarized in Table X and plotted on the map in Fig. 40.

TABLE X

SUMMARY OF THE DATA OBTAINED FROM PREBAITED FEEDING STATIONS
PLACED IN AREAS PREVIOUSLY OMITTED

	Unpoisoned oats	Poisoned oats
Interval (days)	4	2
Number of stations showing no acceptance	8	17
Number of stations showing some acceptance	23	14
Total oats eaten (grams)	1362	154.4
Average acceptance per active station between measurements (grams)	59.2	11.0
Average daily acceptance per active station (grams)	14.9	. . . . . .
Total oats eaten (pounds)	3	.34
Average daily consumption (pounds)—31 stations	.75	. . . . . .
Ratio: poisoned to unpoisoned oats	1:8.8	

As in Table IX, the total poisoned-bait consumption only is shown, as 85 to 90 per cent of the poisoned oats were eaten the first night.

The final acceptance of poisoned oats in these level ditches and the 350-foot strip along the gulch was very small as compared with the original acceptance in the field as a whole. Relatively few rats and mice were left in the level ditches which had not been treated originally. This indicates that a large number of the rats in this area came the full distance to the original stations in the adjacent level ditches (see Fig. 40). There remained a few rats and mice who had escaped the first poisoning because of this increased distance between the original lines of stations. Judging from the results obtained in this test, we cannot expect complete control when the lines of feeding stations are spaced 250 feet or more apart, without greatly increasing the length of the baiting period.

Unpoisoned Oats Following the Poisoned: On April 22, after six days of poisoning, unpoisoned oats were again exposed for four days in the original 255 stations. Out of this number there were only 34 stations (13 per cent) in which the oats had been disturbed or some slight amount eaten during this four-day period. A total of 1.1 pounds of unpoisoned oats was eaten, averaging .27 pound per day, or slightly over one per cent of the average daily amount consumed before poisoning. Judging from the size of the droppings left, mice or young rats were the chief survivors.

The stations showing a return of rodents are enclosed in the circles on Fig. 40 and were found to be in groups on the edges of the areas omitted in the first poisoning. (See Stations 17, 18, 19, 55, 56, 65, 66, 165, 167 and 169.) At these points the station routes were 350 or more feet apart. This evidence shows that some rats had been left in the wider areas omitted in the first poisoning. One remaining group of stations (148, 149 and 150) was located along the gulch next to an unpoisoned area. Here again, rats survived where the spacing between stations was too great. It is possible that young rats just past the weaning stage, traveling in a

Fig. 39. A graphic picture of the distribution of
After Doty
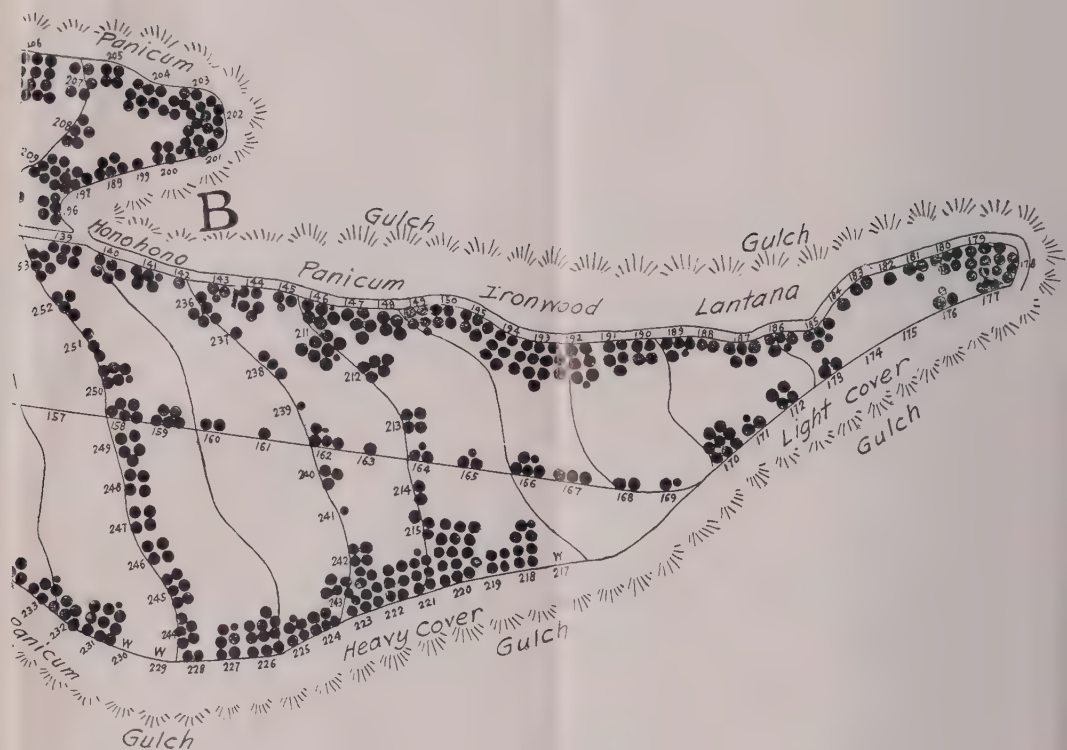
ILAUEA SUGAR PLANTATION CO.

FIELD 20

ntrol – Showing numbered feeding stations with amounts of poison consumed

LEGEND

● = 11 Gms. Poisoned Oats Eaten

• = 5½ ʺ   ʺ   ʺ   ʺ

W = Station Washed Out.

AREAS :
  A = 45.24 AC.
  B = 33.90 AC.

of rats in the field in relation to natural cover.
loty (22).

Pasture

Pasture

Pasture

Pasture

Cut for
Seed

256

257

258

259

260

NORTH

A

Drain

87

56 55

65 66

51

W

287 286 285 284 283 282 281 280 279 278 277 276

17

18

19

Big Cane Road To Lighthouse

R.R. To Kahili

Very Young Cane

KIL

Scale 1" = 261'

AREAS :
A = 45.24 AC.
B = 33.90 AC.
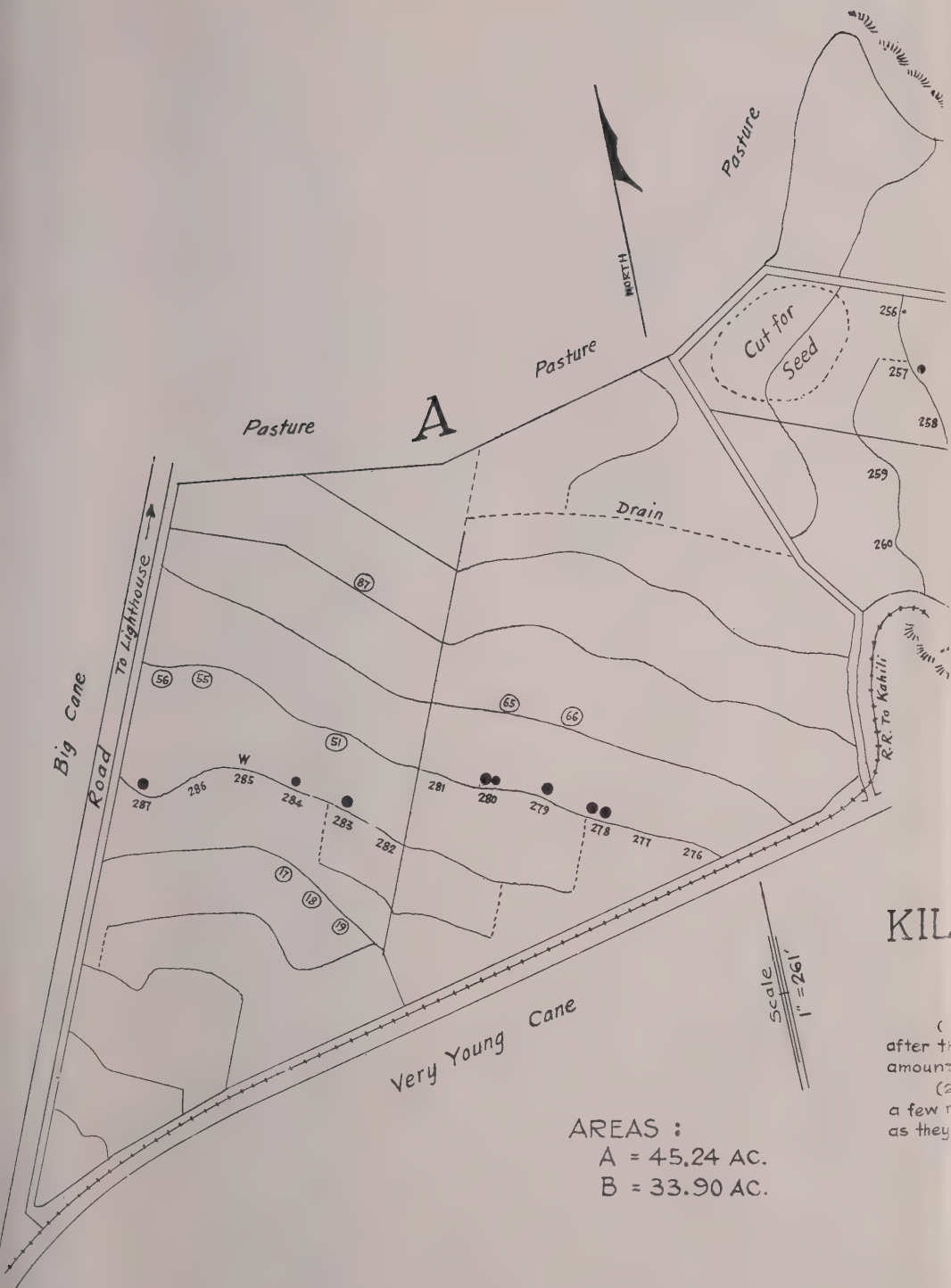
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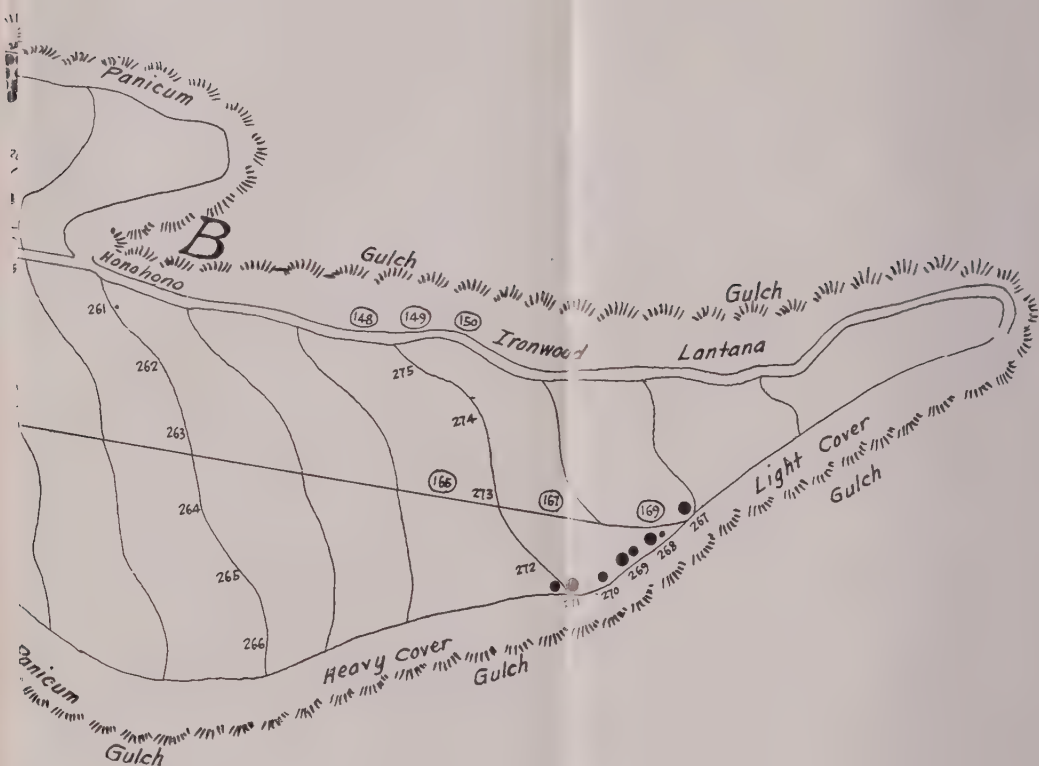
...AUEA SUGAR PLANTATION CO.

FIELD 20

RAT CONTROL

) Showing numbered feeding stations which were placed 12 days
e first campaign (see Fig.   ) in areas previously omitted; with
= of poison consumed at each.

. Showing numbered (in circle) original feeding stations to which
:ts and mice returned to eat unpoisoned grain at the same time
ad come to the stations in (1) (see text)

LEGEND

● = 11 Gms. Poisoned Oats Eaten.
• = 5 " " " "
W = Station Washed Out.
○ = Stations referred to in (2).

Fig. 40. After Doty (22).

wider circle each day had at last moved far enough from their nest to contact one of these feeding stations.

Poisoned bait was again (April 26) placed in the 34 stations having the slightest disturbance of the unpoisoned oats during the four-day period. Only six stations showed any measurable consumption, a total of .09 pound or less than 4/10 of one per cent of the amount of poisoned bait eaten originally, which is negligible.

Labor and Materials: There were 287 stations in this 79-acre field which is an average of 3.6 stations per acre. The labor and materials used in a 9-day schedule of baiting and poisoning may be summarized as follows:

Labor: 1st trip—Distributing the stations (should place and fill about 20 stations per hour) .... 16 hours

2nd trip—Refilling the stations, 4 days later (should cover 22–25 stations per hour) .... 11 hours

3rd trip—Picking up any remaining unpoisoned oats and placing poisoned oats in all stations (2 to 3 days later)....................... 13 hours

4th trip—Picking up stations (3 or 4 days later)........................ 13 hours

Total   52 hours

Materials: Unpoisoned rolled oats .... 110 pounds
Poisoned rolled oats .... 25 pounds
Coconut oil .... 3 gallons

The exact cost figures are omitted because they would not apply to other conditions. However, the total costs in labor and materials are not more, and in many instances are less, than the total cost of previous rat-control methods which made use of torpedoes or sausage baits.

Summary: These studies confirmed our previous findings and proved that the rats at Kilauea would respond to the feeding-station method in a satisfactory manner, as they did on Oahu plantations.

The greatest concentration of rats occurred along the gulches and wasteland where permanent cover is always present. This suggests that an early intensive campaign be concentrated along natural rat harbors near young cane. The feeding-station method is especially adapted to this scheme of control. The results of this test would indicate that we cannot expect complete control when the lines of feeding stations are spaced 250 feet or more apart, without greatly increasing the length of the baiting period.

After six days of poisoning, a return to unpoisoned bait gave consumption of only one per cent of the original average daily amount, showing a very small remaining population, which would not warrant an immediate re-poisoning. It would be more practical to repeat the treatment in two to three months, giving the young rats a chance to mature enough to travel, but before another generation of young could develop. For practical purposes three days' exposure of poisoned bait is sufficient as only one per cent additional oats was eaten during the second three-day period.

The cost of labor and materials, not including transportation and investment in equipment, need not rise above from 30 to 40 cents per acre for one poisoning. This charge would cover the installation and necessary visitations of an average of four stations per acre for a period of nine days.

Kilauea Experiment No. 2: The purpose of Experiment No. 2 was to draw the rats out of a field drain or gulch between Fields 10 and 1. The cane in these fields had been harvested about April 1, 1937, and the rats in large numbers had been forced to move into the heavy growth of panicum in the gulch. Their presence was definitely indicated by much freshly eaten waste cane left along the edges of the field. Two small direct poison skirmish tests using sausages, oat briquettes and loose oats placed in standard feeding stations resulted in very poor acceptance. Trapping was resorted to beginning April 15, by K. Harada, Agriculturist. His catch in traps spaced 20–25 feet apart was good, ranging from 15 to 20 rats per 100 trap-days. After 10 days the traps were moved farther down the gulch toward the sea and a set of 59 feeding stations, spaced 40 feet apart, was placed along the edge of the panicum grass cover (see Figs. 41 and 42). Starting April 26 these stations were kept baited with unpoisoned oats for seven days followed by poisoned oats for seven days. At the end of this period unpoisoned oats were again placed in the stations and, after three days, an examination was made to check the thoroughness of the poisoning.

The data were recorded, station by station, and are summarized in Table XI. The daily averages in total pounds of oats eaten in 57 stations are plotted in Fig. 43. Of the original 59 stations, only two remained inactive throughout, due to poor judgment in placement.

Fig. 41. Typical panicum grass-covered drain in Field 1, Kilauea Sugar Plantation Company, where Experiment No. 2 was carried out. This excellent rat harborage was heavily infested following the harvesting of adjacent cane areas. After Doty (22).

Fig. 42. Edge of panicum grass-covered drain in harvested area of Field 10 showing feeding stations being placed. The consumption of unpoisoned bait at the active stations just previous to poisoning amounted to an average of 80 grams per night, which was the highest for any field studied at Kilauea. Since these stations were spaced only 40 feet apart, this high consumption of bait indicated that an abundance of rats had taken refuge in this natural rat harborage. After Doty (22).

Experiment 2

KILAUEA S.P.CO. FIELD 10
Graph Showing Average Daily Consumption In Total
Pounds Of Rolled Oats From 59 Feeding Stations
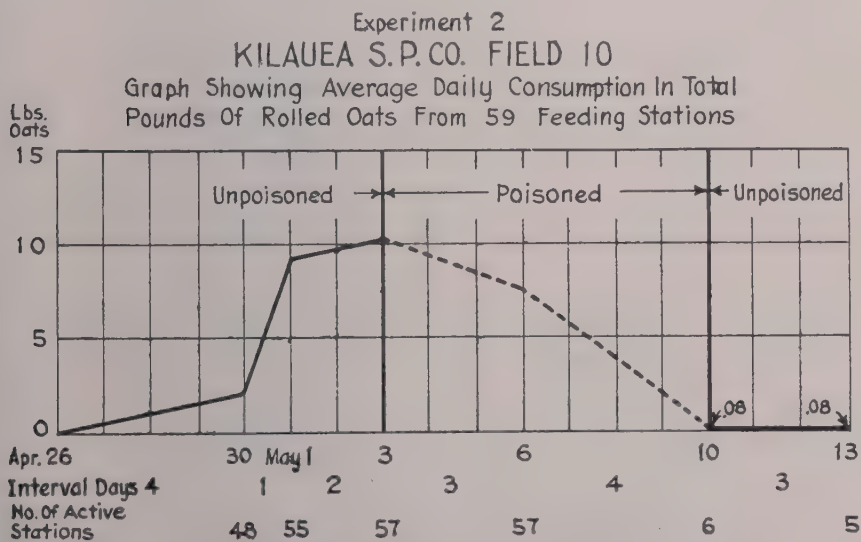
Fig. 43. From Table XI. After Doty (22).

TABLE XI

SUMMARY OF THE DATA OBTAINED FROM KILAUEA EXPERIMENT NO. 2

	Unpoisoned oats			Poisoned oats		Unpoisoned oats
Interval (days)	4	1	2	3	4	3
Number of stations showing no acceptance	11	4	2	2	53	54
Number of stations showing some acceptance	48	55	57	57	6	5
Total oats eaten (grams)......	4239	4163	9149	3382	40	120
Average acceptance per active station between measurements (grams)	88.3	75.6	160.5	59.4	6.8	23.8
Average daily acceptance per active station (grams)	22.0	75.6	80.2	......	......	7.9
Total oats eaten (pounds).....	......	......	38.6	......	7.53	0.25
Total oats eaten during each interval (pounds)	9.3	9.2	20.15	7.45	.08	.25
Average daily consumption (pounds)	2.3	9.2	10.1	......	......	.08
Ratio: poisoned to unpoisoned oats			1:5.3			

Typical of all prebaited-feeding tests, the number of active stations as well as the average consumption per station increased rapidly for five or six days, then levelled off as maximum consumption was approached.

When poisoned bait was applied there was a drop in total consumption of 2.5 pounds or 25 per cent below the maximum of 10.1 pounds of the preceding day. This is a greater decline in consumption than in the first experiment but subsequent studies have shown it to be normal. Again there was almost no poisoned bait consumption after the third day. This test gave further evidence that three or four days exposure of poisoned bait was sufficient.

Unpoisoned oats were again returned to the feeding stations to test the effectiveness of the poisoning. Only four stations showed a measurable consumption for the three days, averaging only 8/100 pound per day or 8/10 of one per cent of the daily consumption before poisoning. This indicated that a few mice or rats still existed in the treated area or had come from greater distances to the food. This border effect will be less when the treated areas are in larger units.

After efforts of direct poisoning were ineffective and even following intensive trapping for several days, this group of feeding stations, closely spaced along the field drain covered with panicum grass and adjacent to a recently harvested field, still gave the highest average consumption of poisoned bait per station for any test conducted up to that time.

COMPARISON OF THREE METHODS OF POISONING RATS AT FIELD-FEEDING STATIONS:

Fieldmen are vitally interested in the efficiency of any modifications of field poisoning which may reduce labor requirements. Field studies of this nature are plagued by variables such as the difference in density of the rat population from field to field, and the unknown amount of reinfestation which follows a poisoning period. The amount of reinfestation, in turn, depends on the nature and position of adjacent rat cover. These unmeasured factors prevent a direct comparison of one treatment in one area with another treatment in another area. Yet the relative efficiency of different treatments has been obtained in a manner discussed below.

The actual consumption of poisoned oats in pounds or grams per acre was determined for each of two successive periods and then added together. This total consumption per acre for the two periods was converted into per cent as 100. Then the consumption of each period was calculated in per cent of this total. Thus, the per cent consumption of poisoned oats during the first period compared with that consumed during the second period gave an index figure which was used to compare the efficiency of one treatment in one field with a different treatment in another field. Even this comparison was subject to some further error because of the unknown amount of reinfestation which took place between the first and second periods of poisoning.

The staff of Kaeleku Sugar Company cooperated in the experimental poisoning and recording of the consumption of poisoned oats from seven fields of cane. The first tests of this nature were completed in June 1943 and a second series of studies
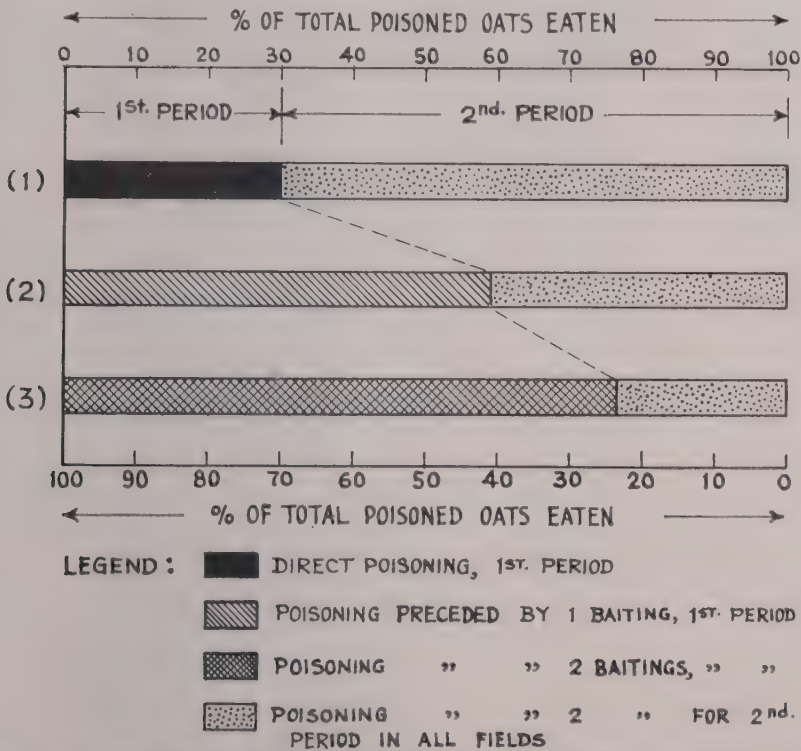
Fig. 44. Graphic presentation showing relative amount of poisoned oats eaten per acre during each of two successive periods of treatment expressed in per cent of the total consumed for both periods. The treatments applied were:

(1) Direct poisoning in the first period, followed by a standard prebaiting cycle in the second period (average of three examples).
(2) One round of baiting and one round of poisoning in the first period, followed by a standard prebaiting cycle in the second period (average of two examples).
(3) Standard prebaiting cycle in the first period followed by a standard prebaiting cycle in the second period (average of two examples). (From Table XII.)

The term "prebaiting" includes the baiting with unpoisoned oats followed by poisoned oats. (From Table XII A.)

was finished in March 1944. Feeding stations were placed 60 to 70 feet apart, which is regular plantation practice. Thallium sulphate was used as the poison in all tests at the rate of one pound to 200 pounds of rolled oats.

The fields chosen for this study were poisoned for two successive periods for each of the three treatments.

The following differential treatments were installed and studied: (A) Direct poisoning for the first period, followed by a standard prebaiting cycle (two rounds of baiting and one of poisoning) in the second period; (B) One round of baiting and one round of poisoning for the first period, followed by a standard prebaiting cycle in the second period; and (C) A standard prebaiting cycle for the first period followed by a standard prebaiting cycle in the second period.

The results of these tests have been summarized in Table XII and are shown graphically in Fig. 44.

TABLE XII
THE CONSUMPTION OF UNPOISONED AND POISONED OATS BY RATS IN FIELDS RECEIVING DIFFERENTIAL TREATMENTS

First period—differential experimental treatment

	Field no.	Acres	No. of stations	Stations per acre	Unpoisoned Lbs.	Poisoned Lbs.	Ratio to un-poisoned	Ozs. per acre	Gms. per station	Gms. per acre	
							Direct poisoning				
(A)	21C	19	170	9.0	....	3.5	....	2.95	9.3	83.6	(a)
	40	50	300	6.0	....	4.5	....	1.4	6.8	40.8	(c)
	21E	45	230	5.1	....	5.0	....	1.8	9.9	50.4	(c)
					One round of baiting and one round of poisoning						
(B)	21F	40	235	5.9	13.5	3.0	4.3	1.2	5.7	34.8	(f)
	21F	13	81	6.2	4.5	6.5	0.7	8.0	36.4	226.8	(g)
					Standard prebaiting cycle						
(C)	21E	45	274	6.1	64.5	19.0	3.4	6.7	31.4	191.5	(i)
	21P	58	183	3.2	53.0	10.0	5.3	2.8	24.8	78.2	(d)

Second period—standard prebaiting cycle for all

	Unpoisoned Lbs.	Poisoned Lbs.	Ratio to un-poisoned	Ozs. per acre	Gms. per station	Gms. per acre		Total poisoned for both periods Gms. per acre	Relative amt. in % for each period First	Second
	Standard prebaiting cycle									
(A)	27.0	12.0	2.2	10.1	32.0	286.5	(b)	370.1	22.6	77.4
	37.5	8.5	4.3	2.6	12.9	77.1	(d)	117.9	34.6	65.4
	22.5	10.5	2.1	3.7	20.7	105.8	(e)	156.2	32.2	67.8
									29.8	70.2
	Standard prebaiting cycle									
(B)	8.5	1.0	8.5	0.4	1.9	11.3	(e)	45.3	75.1	24.9
	31.5	8.5	3.7	10.0	47.6	296.6	(h)	532.4	43.0	57.0
									59.0	41.0
	Standard prebaiting cycle									
(C)	44.0	8.5	5.1	3.0	14.1	85.7	(j)	277.2	69.1	30.9
	8.5	2.0	4.2	0.5	4.9	156.0	(e)	93.8	83.4	16.6
									76.3	23.7

(a) 9 days direct poisoning.	(f) 3 days unpoisoned bait—6 days poisoned bait.
(b) 10 days unpoisoned bait—10 days poisoned bait.	(g) 9 days unpoisoned bait—8 days poisoned bait.
(c) 6 days direct poisoning.	(h) 10 days unpoisoned bait—4 days poisoned bait.
(d) 6 days unpoisoned bait—6 days poisoned bait.	(i) 9 days unpoisoned bait—10 days poisoned bait.
(e) 6 days unpoisoned bait—4 days poisoned bait.	(j) 8 days unpoisoned bait—6 days poisoned bait.

It should be noted here that the interval of poisoning in several cases was too long due to bad weather and poor labor turnout (poisoned bait was exposed eight to ten days).

Direct poisoning in the first period was not effective in controlling the rat population in the three fields used in the test. A high rat population was still present after the treatment and was dealt with by the two baitings and a poisoning given during the second period. Out of the total consumption of oats during the two periods, the direct poisoning period (first) accounted for only 23 to 35 per cent. Direct poisoning was least efficient in Field 21C, which had the highest rat population, and most efficient in the Field 40 harboring the lowest rat population.

One round of baiting was better in one case and much better in the other instance than direct poisoning which was discussed above, but both treatments left many rats remaining to be killed during the second period of standard prebaiting.

Two baitings (standard practice) in the first period in two fields (21P and 21E) serve as checks on the other treatments. Again we find that the highest per cent of total consumption (83.4) was obtained in Field 21P which had the lower rat population. Some of the remaining 16.6 per cent of rats caught in the second period must have been migrants which are the source of error mentioned earlier in this discussion.

Although the results of these tests should not be interpreted too rigidly, due to the small number of experiments, yet they indicate definitely that *two baitings followed by poisoning is the most efficient of the three methods under test.*

Perhaps it should be explained here that the difference between one baiting and two baitings is one of *time of exposure* of a *surplus of unpoisoned food.* One baiting normally extends over a period of three or four days while two baitings generally total six days or even more. When a single application of one baiting is made and the period of exposure extended to six days without renewal or checking of the food, all of the food may be eaten in the first three days leaving the pans empty for the remaining three days. This would not be equivalent to the two baitings of six days duration with surplus oats available for the full time.

ACCEPTANCE OF POISONED OATS:

The amount of poisoned oats that is accepted in comparison with unpoisoned oats, under the prebaited feeding-station method, is of vital interest. All prebaiting experiments have shown a drop in poisoned-bait acceptance when compared directly with the acceptance of unpoisoned oats on the last night of the baiting period. The average consumption of poisoned oats, expressed in per cent of the best day's acceptance of unpoisoned oats, is shown in line 3 of Table XIII for several field experiments. The average per cent of acceptance of poisoned oats in five experiments in the low-reinfestation group was 58 per cent; nine experiments in the high-reinfestation group showed an acceptance of 76.4 per cent; and the mean for the two groups of 14 tests was 68.1 per cent.

The reasons for such wide fluctuations are not clearly evident, although many factors must influence the final results. Weather conditions may influence the consumption of either unpoisoned or poisoned oats on a particular night. Some detection of the poison may even occur, depending on the moisture content or freshness of the bait. The most logical explanation of this decreased acceptance on the first

night of poisoning is that most rats visit and eat at an unpoisoned station more than once during the hours of darkness of any one night, but when poisoned bait is introduced at a station, the rats make only the first visit and lose their appetites by the time they are ready for their second meal. This is almost certainly the case when zinc phosphide is used, as the victims are dead within from six to eight hours. The quicker action of the zinc phosphide probably accounts for its generally reduced acceptance as compared with thallium sulphate. This point is discussed in greater detail under the heading, *"Zinc Phosphide—Cage Tests."*

On the other hand the per cent of acceptance of poisoned bait might appear unduly high if the unpoisoned oats were insufficient to supply all demands during the last night before poisoning.

However, these factors are not serious indications of any inefficiency of the bait, since under the prebaiting plan most rats consume a heavy overdose of poison ranging from as high as five to seven times a minimum lethal dose (M.L.D.) This high ratio of poisoned bait eaten to the minimum lethal dose is presented graphically in Fig. 51 under the subject of "Thallium Sulphate."

TABLE XIII
SUMMARY OF POISONED OATS CONSUMED IN 15 FIELD EXPERIMENTS

Amount of reinfestation: fields grouped as	High	Medium	Low
Number of experiments	9	1	5
Average number days—interval between 1st and 2nd poisoning	9.8	9.8	6.4
Average consumption of poisoned oats in 1st period (in % of the best day of 1st unpoisoned period)..................	76.4	60.5	58.0
Average consumption of poisoned oats in 2nd period (in % of the best day of 1st unpoisoned period)..................	15.6	5.9	2.3
% reinfestation (range)	12.8–30.8	....	0.4–4.0
% reinfestation (mean)	21.3	9.8	2.5*

*Three cases out of five were calculated on basis of unpoisoned oats consumed only, since second round of poisoned bait was not applied.

THE PROBLEM OF REINFESTATION:

One of the important phases of rat control is the rate of reinfestation of an area following a poisoning campaign. The rate of increase of rats in a newly poisoned area is governed, not so much by the density of the previous population, as by the proximity of rat harborage, and the ratio of the size of the treated area to the field perimeter that is exposed to untreated rat-infested terrain. The results of several experiments in rat control conducted in widely separated fields were brought together for study and are summarized in Table XIII. In order to make any direct comparisons it has been necessary to convert the quantities of oats consumed in two successive periods of poisoning into per cent of the consumption of unpoisoned oats on the day of its highest acceptance before the first poisoning. The percentage of poisoned oats eaten during the second period represents the amount of reinfestation that has taken place during the interval between the two periods.

The experiments used in this table were arranged in three groups in a descending order of reinfestation (*i.e.,* high, medium and low). The nine experiments in the first group showed extremely heavy reinfestation (13 to 31 per cent), in a very short period of from 9 to 11 days. In these tests, the feeding stations were placed in either long single lines laid out across untreated land covered with heavy vege-

tative rat harborage, or in long narrow fields of cane surrounded by much larger areas of heavily rat-infested wasteland.

A sample of an intermediate amount of reinfestation (9.8 per cent) is illustrated by Experiment 40 (Kailua). The stations under study in this test were located along the edges or inside of a very small field of previously treated cane but adjacent to some untreated rat harborage.

The last group of five experiments, representing areas of very low rat reinfestation (0.4 to 4.0 per cent), was located in large solid blocks of treated cane with a minimum per cent of the areas exposed to heavy migration. In these examples the feeding stations showing reinfestation on the second unpoisoned and poisoned period, *as would be expected,* were always located on the perimeter of the area. This series of experiments shows the very high percentage of reinfestation that occurs in a treated corridor and the relatively less infestation to be expected as the treated area becomes larger and more compact. A specific example which illustrates this principle is given in Fig. 58 and in the comments following an experiment using L-Tox (Experiment 41).

Likewise, the treatment of large areas of a plantation as one continuous block will decrease further the amount of reinfestation that can occur between poisoning cycles. This is corroborated definitely in the results of the rat-trapping indexes at Kauai Variety Station which cover a five-year study of rat migrations into a large area of cane protected by prebaited feeding stations (23, pp. 79–80). A study of the changes in rat population in this area with the elapsed time following a baiting and poisoning period showed that no significant or damaging increase took place during an interval of 3½ months between poisoning cycles. It was evident that this area did not harbor a permanent resident rat population and that the few rats which had been caught (average 1.5 rats per 100 traps per day) were transients coming from a strip of wasteland in an adjacent gulch. The usual seasonal variation in rat population in this cane area was greater than the increase due to the length of time between poisonings.

DETECTION OF TOXIC SUBSTANCES IN FOOD:

Rats possess a very delicate sense of taste which parallels closely the taste sense of humans. Richter and MacLean (67, p. 1) have reported that, "Results of self-selection experiments showed that under a wide variety of circumstances rats have the ability to regulate their sodium chloride intake according to their salt needs." Again, Richter (66, p. 371) found that, "The salt taste threshold of 20 normal rats averaged 0.055 per cent, that is, the animals detected salt in solutions of approximately one part of salt to 2,000 parts of water." Richter and MacLean (67, p. 6) reported further that, "The average concentration at which they [humans] first definitely recognized the taste of salt was 0.087 per cent with a median of 0.065 per cent." Thus it is apparent that, "The threshold at which humans first recognized the salt taste closely agreed with the threshold found in rats."

Richter and Clisby (70, p. 157) also reported that, "Rats first showed that they could distinguish a sucrose solution from distilled water in concentrations of 0.5 per cent; human beings first recognized . . . a 'sweet' taste in concentrations of 0.41 per cent. . . . Thus for these two common substances human beings and rats have very nearly the same taste thresholds."

The ever-present problem of poison detection by rats is confirmed by Richter and Clisby's recent taste-threshold study (70, p. 161) of phenylthiocarbamide, a highly bitter substance, toxic to rats.* "The results of three experiments have demonstrated that most of the rats avoided this highly toxic phenylthiocarbamide even in very low concentrations." When the rats' drinking water contained only three parts of phenylthiocarbamide in 1,000,000 (0.0003 per cent) they definitely detected the poison and shied away from it. Human beings recognized a difference between the phenylthiocarbamide solution and distilled water over a wide range but the maximum frequency fell at 0.0003 per cent also. Richter and Clisby (70, p. 164) state that, "The concentration at which human subjects first recognized a bitter taste ranged from 0.00001 to 0.2 per cent. The maximum frequency for the 261 individuals again fell at 0.0003 per cent. . . . The concentration at which 95.5 per cent of the rats refused to take the phenylthiocarbamide solution fell below the lethal doses." Yet, "It was found that when phenylthiocarbamide was mixed with regular food most of the rats would eat enough to kill themselves. This may be explained by the fact that, due to the insolubility of phenylthiocarbamide, they swallow it before they taste it. When the phenylthiocarbamide was placed in a 20 per cent dextrose solution, 50 per cent of the rats drank sufficiently large amounts to kill themselves. The sweet flavor of the dextrose may have concealed the bitter taste of the phenylthiocarbamide."

However, rats can detect toxic substances in natural foods. Franke and Potter (31, p. 331) have furnished an excellent example of this acute selectivity from their experimental feeding to rats of wheat samples containing small but variable amounts of selenium. They demonstrated, " . . . conclusively that rats possess the ability to recognize diets of varying selenium content."

Studies to determine the degree of detection and subsequent refusals of poisoned bait have been continued from time to time in Hawaii. In a small test (Experiment 25) at the Manoa Substation the rats showed little preference between thallium-poisoned and unpoisoned briquettes on the first night of exposure, but after the third night the surviving rats showed a decided preference for the unpoisoned rolled oat pellets. The consumption of unpoisoned oats increased with each succeeding night of exposure while the poisoned oats remained practically untouched. From these tests it appears that rats readily detect poisoned material even though thallium is recognized as being both odorless and practically tasteless.

A test (Experiment 24) at the Waimanalo Sugar Company compared the consumption for four nights of thallium-poisoned and unpoisoned rolled barley vs. poisoned and unpoisoned rolled oats placed in adjacent pans. Here, the rats ate ten per cent less barley and 27 per cent less rolled oats from the poisoned pans than they did from the unpoisoned pans.

Another test (Experiment 37—Kailua Substation Oct. 1939) was planned to determine to what extent rats can distinguish between unpoisoned and thallium-poisoned grain fed to rats under the prebaiting system. Standard feeding stations were placed in pairs, with covers touching, and the pairs spaced 50–80 feet apart

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*One to 2 mgm. of phenylthiocarbamide is sufficient to kill rats in only a few hours. Evidently based on this original work by Richter, the E. I. Du Pont de Nemours & Company has developed a new organic rat poison, Alpha-Naphthylthiocarbamide, which is being tested in Hawaii under the trade name "Antu."

throughout the selected area. For the non-poisoning period of seven days, both pans of each pair were baited to build up a rat clientele. Corn oil was used uniformly throughout the test. After the baiting period one pan of each pair was baited with poisoned rolled oats (1–200) while the other remained baited with unpoisoned oats. Each day the position of the individual poisoned and unpoisoned pans was reversed to overcome any possible advantage due to location. Poisoned and unpoisoned oats were exposed in this manner for a total of 14 days. At the end of this time all unpoisoned pans were withdrawn leaving poisoned oats only at all stations showing activity. The detailed consumption data were tabulated and summarized. Only the summarized data are presented in Tables XIV and XV. Graphic presentations are shown in Figs. 45 and 46.

TABLE XIV

SUMMARY OF RESULTS OF TESTS WITH POISONED VERSUS UNPOISONED OATS —STATIONS IN PAIRS 50–80 FEET APART

Interval (days)	1st period (7 days) All unpoisoned				2nd period (14 days) Odd numbers poisoned—even numbers unpoisoned										3rd period (3 days) Poisoned only
	4		3		4		3		2		2		2		3
	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd
No. of active stations	45	45	48	47	48	48	18	36	7	31	3	31	1	28	13
Total oats eaten (grams)	2828	2778	3748	3622	1238	3333	64	683	23	521	3.4	473	4.5	944	68
Avg. daily consumption (grams)	707	695	1249	1207	310	833	21	229	11	260	1.7	236	1.5	314.5	17
Avg. daily consumption (grams) (odd+even)	1402		2456.7		1143		250		271.6		238		316		17
Consumption— % of highest day	57.1		100.0		46.5		10.2		11.1		9.7		12.9		..

TABLE XV

SUMMARY OF RESULTS COMPARING ACCEPTANCE OF UNPOISONED AND POISONED OATS

	7-day blank test period Unpoisoned		14-day treated period	
	Odd nos.	Even nos.	Poisoned Odd nos.	Unpoisoned Even nos.
Average number of stations...............	47	46	15	35
Number of measurements made per period..	2	2	5	5
Total oats eaten (grams).................	6576.1	6400.3	1332.4	5952.7
Total difference (grams)	+175.8	....	....	+4620.3
Total difference (%)	+ 2.7	....	....	+ 346.8

Total unpoisoned oats consumed—21 days..	18,929 gms.
Total poisoned oats consumed—14 days....	1,332.4 "
Ratio: poisoned to unpoisoned oats........	1:14

This table shows the low consumption of poisoned compared with unpoisoned oats when both are exposed together at the same time. This condition is also reflected in the unfavorable ratio of 1:14.

During the unpoisoned blank test period the total consumption of all of the odd-numbered pans was 2.7 per cent greater than the adjacent even-numbered pans. This represents the fluctuation that occurred in the field due to chance alone. These odd-numbered pans became the poisoned-pans during the poisoning period.

The first reading after four days* of poisoning showed good acceptance of the bait indicating little actual differentiation between the poisoned and unpoisoned pans, but many of the rats which had eaten from the unpoisoned pan at first, began to be selective and continued to eat from the unpoisoned pan in spite of its shifting position.

PROJECT A-108 EXPERIMENT 37
POISONED VS. UNPOISONED OATS IN ADJACENT PANS
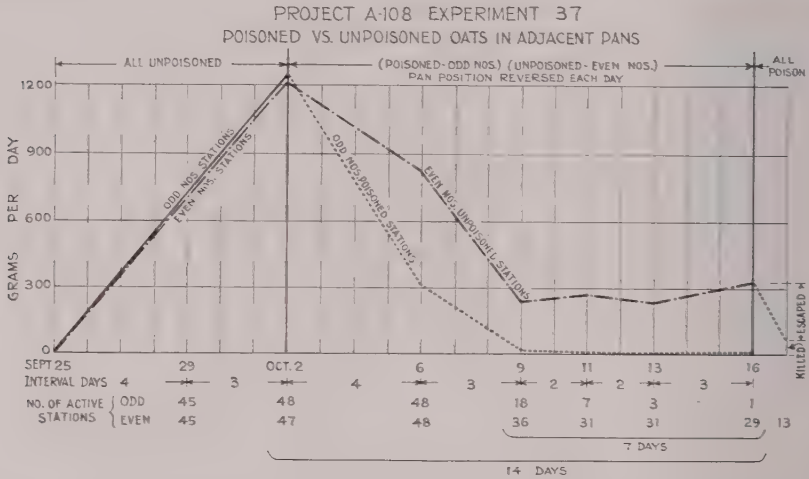
Fig. 45. The average total amounts, in grams, of poisoned and unpoisoned rolled oats consumed per day by rats at forty-eight pairs of feeding stations, following a period when only unpoisoned oats were offered at all stations (from Table XIV).

PROJECT A-108 EXPERIMENT 37
POISONED VS. UNPOISONED OATS IN ADJACENT PANS
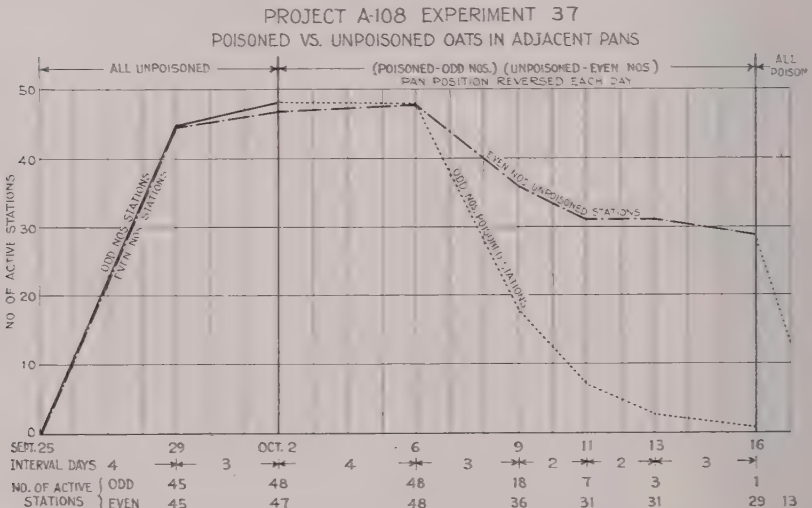
Fig. 46. The number of poisoned and unpoisoned pans which became active out of a total of forty-eight pairs of feeding stations, following a period when only unpoisoned oats were offered at all stations (from Table XIV).

*If readings could have been made at two-day intervals the curve would have started to decline after two instead of four days.

The oats in the poisoned pans were not touched after the seventh day of exposure but at the same time the unpoisoned oats in 36 out of a possible 48 pans showed activity amounting to about 25 per cent of the original total consumption before poison was introduced (see Fig. 45). Thus at the end of 14 days of poisoned bait exposure there were still about 12–13 per cent of the original rat population eating heartily from the unpoisoned pans exclusively and they probably could continue indefinitely with new customers being attracted from greater distances. This demonstrated that these remaining rats could detect which pan contained poisoned oats and therefore they could not be poisoned under the conditions of this test up to this point.

An attempt was then made to see how many of these rats could be poisoned by shifting to poisoned bait only. Accordingly, all unpoisoned oats were removed and fresh poisoned oats placed in all odd-numbered pans. The rats then ate 68 grams of poisoned bait from 13 stations. This amounted to 22 per cent of a previous day's consumption of unpoisoned oats (315 gms. from 29 stations). This would indicate that not over $\frac{1}{4}$ of the final rat population (12–13 per cent of original) was poisoned, leaving about 9 or 10 per cent of the original population which had completely outwitted us in this test.

This test demonstrated that, when an opportunity was offered to choose between poisoned and unpoisoned oats, about 12 per cent of the field rats at Kailua Substation detected poison accurately for an indefinite time even after a baiting period.

This study emphasizes the fact that a baiting period, to create a habit of securing food from specific places, must be followed by *an abrupt change to poisoned bait* over large areas in order to insure continued success in rat control.

ATTRACTANTS OR LURES IN RAT BAITS:

Review of the Literature: According to Hovell (40, p. 136) the idea of adding essential oils to rat baits to enhance their attractiveness has been in vogue for many years. He further stated that, "Recent experiments seem to show that baits which have not been flavored are taken more readily than those which have been thus treated."

Boulenger (8, p. 5) commented in 1919 that, "Food faintly flavored with oils of Rhodium and Aniseed, instead of improving the bait, had the contrary effect." According to O'Connor, Buck and Fellers (59, p. 1379) "The use in foods of oils of caraway, anise, catnip, cinnamon, and peppermint did not enhance palatability of the food to rats." Peppermint oil was reported as "repulsive to rats."

Barnum (6, p. 429) wrote in 1930 that, "Much emphasis has been falsely placed on odors and flavors as attractive factors in rat-bait preparations."

Lubitz, Fellers and Levine (48, p. 103) working at the Massachusetts Agricultural Experiment Station summarized their tests of a number of organics on white rats as follows: "Mono-sodium glutamate; oil of rhodium imitation; extract of cheese imitation; oils of anise, caraway, cinnamon, and peppermint; brewer's yeast powder; two by-products of the manufacture of thiamin from rice hulls; and thiamin chloride were tested in rat baits as lures. These were found to possess no merit as attractants to albino rats."

Somewhat contrary to the findings of Lubitz, *et al,* Richter, Holt and Barelare (65, pp. 354–355) reporting on work at the Psychobiological Laboratory of Johns

Hopkins Hospital found that both the odor and taste of Vitamin B (thiamin chloride) were very attractive to thiamin-deficient rats and that their craving for this vitamin was one of the strongest of all the cravings.

Garlough (36, p. 3) reported that Welch had, ". . . again tested several of the better known essential oils in rat baits and found oil of almonds and amyl acetate to attract some attention but not enough to be significant."

Ward (86, p. 129) has commented that the value of fish oils added to a bait seems to be in "lure" value, but that it was very easy to get too much. As little as, "Five per cent of most of the oils caused a definite detrimental effect on acceptance." He states further that, "Raw linseed oil, when present in from 3–5 per cent of the weight of the entire bait, has given good results. Peanut oil is inferior to peanut butter, and the same thing is true of soybean oil being less satisfactory than soybean lecithin." Ward states that soybean lecithin is a material, ". . . which is available in a wide variety of forms, varying in purity from a crude 'tank settling,' taken from the bottoms of soybean oil processing stills, to a refined substance suitable for use in candy and other human foods. Curiously enough rats prefer tank settlings as long as they are not rancid."

From all of this work we must recognize the fact that many of the essential oils tried out by these various investigators were not attractive and many were even distasteful to rats, but it does not follow that all vegetable or animal oils or other organics are equally objectionable.

The comments of Australian sugar men concerning oils as attractants are of interest here. In 1935 Gard (32, pp. 601–602) reporting on the use of strychnine-wheat torpedoes stated: "When waterproofed with paraffin wax, however, they were not taken at all well; but raw linseed oil made them very attractive. Linseed oil is therefore now used in all baiting, both with traps and poisons. Its attraction for *Rattus culmorum* and *Melomys littoralis* is so definite that many farmers who were not successful in trapping previously, now use only paper and rag soaked in this oil for bait, and have no trouble in catching rats. Oils of rhodium and aniseed showed no attractions, and oil of valerian proved definitely less attractive than raw linseed oil."

In 1938 McDougall (51, pp. 625–626) reported less enthusiastically on the use of oils, stating that: "The actual palatability of baits is not improved, so far as the economic aspect of baiting is concerned, by the addition of linseed or corn oil. These oils are excellent attractants, but they are not appetizers. It seems as if the fundamental fact governing intake is the palatability of the base bait as a food. Such intake is, in different degrees, modified by the several rat poisons at different bait strengths. We do not know of a material (called an 'appetizer') which, when added to a poor bait base or a bait of poor intake, such as phosphorus on bread, will increase the intake."

Bell (7, p. 43) summarized Australia's developing viewpoint in his annual report for 1938 to the Bureau of Sugar Experiment Stations, Queensland, by stating: "It would appear that the addition of linseed oil to poison baits is unnecessary. This material is an excellent attractant for trapping purposes, but it is not an appetizer, however, and does not improve the normal intake of baits of poor palatability."

By 1940 McDougall (52, p. 191) appears to feel that the addition of oils is of little consequence when he writes: "The addition of such materials as linseed oil or

corn oil to baits does not improve or otherwise interfere with the efficiency of the baits."

Review of Hawaiian Work: In our study of vegetable oils in Hawaii, we have not tried to make a poor bait palatable, but rather to aid the rats to find quickly the bait containing a good rat food. At the same time we have endeavored to use an oil which would be an appetizer* as well as an attractant. Oils that are extracted from preferred rat foods would seem to be the most promising.

W. P. Naquin, formerly Manager of Honokaa Sugar Company, originated and developed the paraffin-dipped paper torpedo. This bait package was sufficiently waterproof to make the field distribution of poisoned wheat practical, and it continued in wide use for years.

About 1931 it was noted that many torpedoes remained untouched in the fields on Kauai, and there was a definite need for some scheme to attract the rats or cause them to investigate these torpedoes.

With this in mind, the writer (14, p. 117) tried out certain vegetable oils as waterproofing materials for thallium-wheat torpedoes with the hope that the odors of the several oils might prove a special attraction to the rats. Experiment 1-A, comparing torpedoes dipped in corn oil, sunflower oil, coconut oil, and paraffin, showed that corn oil was preferred, the rats having taken 61.9 per cent of the corn oil, followed by 41.2 per cent of the sunflower oil, 39 per cent of the coconut oil, and only 10.5 per cent of the paraffin-dipped torpedoes. A duplicate test (1-B) showed percentages ranging somewhat lower than the former experiment, due to the larger number of torpedoes put out in a comparatively small area. The percentages were: corn oil 42.6 per cent, followed by sunflower oil with 27.8 per cent; coconut oil with 17.6 per cent, and paraffin oil with only 9.8 per cent.

Another skirmish test (2-A) (14, p. 121) compared dry thallium wheat in a corn-oil-dipped wrapper with corn-oiled wheat in an undipped wrapper. These treatments were checked with paraffin-dipped torpedoes. The results showed 30 per cent of the dry wheat torpedoes dipped in corn oil were taken; 18.3 per cent of the torpedoes of corn oil in wheat with plain non-oiled wrappers were taken, while only 13.3 per cent of the paraffin-dipped torpedoes were taken. The trend was definitely against paraffin-dipped torpedoes and in favor of the torpedoes having the most corn oil absorbed into the paper wrapper. When dry wheat and corn-oiled wheat were made into torpedoes and both dipped in corn oil the rats did not discriminate between them in skirmish test 2-B (14, p. 121). The torpedoes under study in the above tests were grouped into stations, each station having an equal number of each kind of torpedo under test. After having found the station, the rats were free to choose the various kinds of torpedoes. The ability of the rats to locate one or the other of the baits could not be detected by this group method.

To test the rats' ability to find isolated torpedoes, single torpedoes of corn oil and paraffin were placed 10 to 15 feet apart, alternating, along the edge of big cane (Experiment 4) (14, p. 122). The final percentages of this test (at Kailua) were more favorable to corn oil than in the previous test, 73.2 per cent of the corn-oil-

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*We should recognize a distinction between substances which are essentially attractants and those that are appetizers as well. No doubt rats are attracted by some essential oils, but it does not necessarily follow because some odor may attract rats, that they like food heavily flavored with it.

dipped torpedoes being taken compared with 26.6 per cent of the paraffin-dipped torpedoes.

Having determined that corn oil was attractive to rats, it was desirable to attain greater waterproofing characteristics. Accordingly mixtures of corn oil and paraffin were made by adding varying amounts of corn oil to melted paraffin. Into these mixtures the fibre-spun-paper torpedoes were dipped by means of a wire basket in the same manner as was done with pure paraffin. Any mixture of corn oil and paraffin was softer and less waterproof than pure paraffin, depending on the amount of corn oil added. It was determined that 175 cc. of corn oil per pound of paraffin was about the upper limit of dilution without seriously injuring the mixture as a water-proofing material. It was found in Experiment 5 (14, p. 123) that the corn oil and paraffin mixture was accepted much better than the pure paraffin.

At Waipio Substation (15, p. 96), out of 200 torpedoes of each kind spaced singly and alternating, 39 straight-paraffin torpedoes were taken compared with 166 corn-oil-paraffin torpedoes. This furnished additional data that corn-oiled poisoned baits were definitely sought after, while pure paraffin-oiled poisoned baits were found merely by accident.

Some skirmish tests (17) in cages conducted in 1935 indicated that rats preferred plain oat cakes as a continuous diet in preference to oat cakes dipped (saturated) in raw linseed oil or a corn-oil-paraffin mixture.* In this study a group of 14 rats were fed for 28 days. Whole wheat, sugar cane and water were supplied at all times. In addition to this, an ample supply of rolled oat cakes was available at all times offering a choice of treatments, i.e., (1) dipped in raw linseed oil, (2) dipped in corn-oil-paraffin and (3) plain oat cakes.

From a total of 608 oat cakes of each kind exposed, the rats showed their preference as follows: (1) plain, undipped, 40.7 per cent; (2) dipped in corn-oil-paraffin mixture, 19.9 per cent, and (3) dipped in raw linseed oil, 10.2 per cent.

The feeding study was continued on the same rats for another 17 days, but with the corn-oil treatment separated from the paraffin. Out of 273 oat cakes of each kind exposed the rats accepted them in the following percentages: plain undipped—62.3; dipped in corn oil—17.5; dipped in paraffin—6.2; and dipped in raw linseed oil—4.6.

It was observed that the plain undipped cakes were progressively more favored, the longer the test was continued. The presence of paraffin with the corn oil definitely reduced acceptance. We are unable to explain why raw linseed oil declined in favor below paraffin in this instance. The rats appeared to become satiated on the excessive amounts of oil soaked into the cakes.

In a small skirmish test (18) at Kailua Substation when corn-oil-paraffin was alternated with raw linseed oil as attractants on thallium-oat torpedoes spaced in the field three to five feet apart, the linseed oil alone was somewhat more attractive (but not significantly so) than the corn-oil-paraffin mixture (48.5 per cent vs. 45 per cent). It is apparent that the presence of paraffin in any amount reduced the acceptance of corn oil.

A field study (19) of the attractiveness of raw linseed oil and corn-oil-paraffin

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*Mixture of 20 per cent of corn oil to paraffin by weight; 175 cc. corn oil per pound of Parowax.

as waterproofing for thallium-rolled-oat torpedoes was carried on at Ewa Plantation in February 1936. The torpedoes were spaced singly three to five feet apart, the two kinds alternating. The area was visited each of the three following days and all torpedoes eaten or missing were noted and replaced to bring the total up to the maximum (191 of each treatment).

The percentages of each treatment for the four days are tabulated below:

	┌─Torpedoes──percentages taken─┐	
	Raw linseed oil	Corn-oil-paraffin
2nd day	90.9	89.8
3rd day	41.4	76.1
4th day	12.8	25.4

In this test raw linseed oil and corn-oil-paraffin were equally attractive the first night when the acceptance was large irrespective of the attractant. On the two succeeding nights after the rats had been thinned out, the remaining population favored the corn-oil-paraffin over the raw linseed oil.

Raw linseed oil and corn-oil-paraffin mixture were compared again on an area at the Hilo Variety Station (20) which was poisoned with torpedoes put out at the rate of 250 per acre. This level (361 torpedoes for each treatment) was maintained for three days and counts made of the number of torpedoes taken for a period of seven days. The results were tabulated as follows:

	┌────Torpedoes taken────┐	
	Raw linseed oil	Corn-oil-paraffin
1st check	43	59
2nd check	19	14
3rd check	15	16
4th check	10	15
5th check	3	0
6th check	0	0
7th check	8	12
	—	—
Total for period	98	116
Per cent taken for period.........	27.1	32.1

The return acceptance of torpedoes occurring on the 7th check was due to harvesting of an adjoining plantation field which caused rats to migrate into the treated area during the progress of the test. Here again, the corn-oil-paraffin mixture led by only a small margin.

However, R. L. Walker of Kaeleku Sugar Company obtained results (Experiment 17-B) strongly favoring raw linseed oil from a similar cooperative test at Hana, Maui, in February 1936. Mr. Walker's results have been summarized as follows:

TORPEDOES EXPOSED, TAKEN, AND REPLACED

Days exposed	┌────Raw linseed oil────┐			┌────Corn-oil-paraffin────┐		
	Exposed	Taken	% of replacement	Exposed	Taken	% of replacement
2	200	173	87	200	78	39
3	200	106	53	200	48	24
	200	82	41	200	43	22
	200	74	37	200	26	13
	—	—	—	—	—	—
Totals	800	435	54.4	800	195	24.4

Number favoring raw linseed oil—240; per cent difference favoring raw linseed oil—55.2.

We could not explain this reversal of acceptance with any degree of certainty, although we suspected paraffin to be the cause.

A test conducted at Waipio Substation in March 1936 (21) compared rolled oat torpedoes dipped in (1) corn-oil-paraffin, (2) crude coconut oil, and (3) raw linseed oil. The area contained a relatively low rat population so the acceptance percentages are low but the comparisons are valid. From a total of 973 torpedoes for each treatment, the following results were obtained.

Treatment	No. taken or opened	Per cent
(1) Corn-oil-paraffin	117.5	12.1
(2) Crude coconut oil	242.5	24.9
(3) Raw linseed oil	251.5	25.8

Raw linseed and crude coconut showed no significant difference in acceptance, but the corn-oil-paraffin was the least attractive of the three. It was thought then that this low acceptance was due to the paraffin. This was confirmed in later work.

Later Eckart (24) carried on an intensive study of the use of oils at The Lihue Plantation Company on Kauai with special emphasis on combinations of oils inside and outside of torpedoes containing wheat or barley. From his Experiment 5 at Lihue (24, p. 161) he concluded that, "A marked increase in effective take is shown for 'corn oil inside and out' over 'corn oil outside only.' Rolled barley was preferred to wheat where the grain was saturated with corn oil but there was no significant difference between wheat and barley with 'corn oil outside only.' " We believe this condition would continue to exist only when there is a shortage of barley and plenty of rats.

"Effective take" as used in this quotation is an index or measure of acceptance (removal) of torpedoes which would be sufficient to kill if eaten; but gives no assurance that the torpedoes were actually consumed.

Eckart (24, p. 161) reported Experiment 6 comparing raw linseed oil inside and out with corn oil inside and out, using both wheat and barley torpedoes. He concluded that, "Under the conditions of this test the rats showed an outstanding preference for 'barley-raw linseed oil inside and out.' " He also concluded from Experiment 7 (24, p. 162) that, "The results show no difference, . . . between 'wheat-raw linseed oil inside and out' and 'wheat-corn oil outside only.' The very poor effective take of the old wheat standard (no oil) is quite apparent." These results are not as clear as they should be due to the many variables being involved in the one experiment. In Experiment 16 comparing coconut oil with raw linseed oil outside barley torpedoes (24, p. 164), " . . . summary shows a questionable preference for 'barley-coconut oil outside only' and 'barley-raw linseed oil outside only.'. . . It might be concluded, then, that under the conditions of this test, coconut oil is just as attractive to rats as raw linseed oil."

In Experiment 17 comparing barley-coconut oil inside and out with barley-coconut oil outside only Eckart found (24, p. 165) that, "The results show a significant increase in effective take for 'barley-coconut oil inside and out.' The significance of the results is brought out very clearly in a study of the total number of torpedoes effective during the 6-day period." We have included Eckart's summary below:

	Total torpedoes effective 6 days
Barley-coconut oil outside only	167
Barley-coconut oil inside and out	239

Another skirmish test (24, p. 166) compared coconut oil inside and out with coconut oil inside and raw linseed oil outside: "The results of this test showed a marked rat preference for the 'coconut oil inside-raw linseed oil outside' oil combination." After obtaining this later result, Eckart (24, p. 169) reported that, "The plantation practice of 'rolled barley-raw linseed oil outside only' has been changed to 'rolled barley-coconut oil inside-raw linseed oil outside.' "

Perhaps this is a case of the raw linseed oil being an attractant but not an appetizer while coconut oil is more of an appetizer than an attractant, but may function as both.

Use of Oil Attractants With the Prebaited-Feeding System: The use of an oil attractant under the prebaited feeding-station plan is quite different from its use under the previous torpedo system. An attractant is considered essential on poisoned torpedo baits because success is dependent entirely on each individual rat actually finding and eating a poisoned torpedo. On the other hand an attractant may be less essential at a feeding station, because only one rat needs to find the station early in the baiting period to insure a large clientele boarding regularly by the time poison is added.

However, when prebaiting was first studied in Hawaii (1936–1938), the adding of oil to both unpoisoned and poisoned bait was adopted as standard practice direct from the previous torpedo work. Since the rats seemed to find the prebaited stations readily, we then desired to know if omitting the oil would cause a serious delay or decline in acceptance.

Corn oil vs. no oil: The problem of attractants was re-examined in November 1939 when Experiments 35A, B, C, and 36 were installed to determine the usefulness of crude corn oil and raw linseed oil under these new conditions.

The regular feeding stations were placed in the field, grouped in pairs 50–70 feet apart, with 4–6 feet between the individual stations of each pair. Only a small amount of oil was used in treating the oats, just enough to give the oats a slight odor. In this minute amount, oil was being used more as an attractant than as an appetizer. Standard hulled rolled oats were used in all of these tests. The poisoned oats contained thallium at the rate of one pound to 200 pounds of rolled oats.

The detailed consumption data were tabulated and summarized. Only the summarized data are presented:

TABLE XVI

CORN OIL VERSUS NO OIL

(EXPERIMENT 35, SECTION A, KAILUA SUBSTATION)

	Unpoisoned oats		Poisoned oats	
	No oil	Corn oil	No oil	Corn oil
Number of days exposed.....................	6	6	3	3
Number of paired stations..................	65	65	37*	37*
Total oats eaten (grams)...................	5032.7	8006.0	447	809
Difference (grams)	......	+2973.3	......	+362
Difference (%)	......	+59.1	......	+81.0
Avg. consumption per station for period (grams)	77.4	123.2	12.1	21.9
Avg. consumption per station per day (6 days— grams)	12.9	20.5	......	......
Significance of difference	......	Very high	......	Very high
Odds by Student's Method..................	......	9999 to 1	......	9999 to 1

*Area of low land flooded the first night of poisoning so the records were lost on almost one half of the stations. This caused the rats to eat more than the normal amount of bait from the remaining stations.

These results showed a definite and reliable superiority for corn oil over the no-oil checks. Corn oil was 59 per cent better than no oil on unpoisoned oats and 81 per cent better than no oil when applied to poisoned oats.

A station-to-station comparison of 65 pairs indicated 58 favored corn oil, 6 favored no oil and one was even. Out of 37 pairs measured during the poisoning period 28 favored corn oil, 4 favored no oil with 5 even.

TABLE XVII

CORN OIL VERSUS NO OIL

(EXPERIMENT 35, SECTION B, KAILUA SUBSTATION)

	Unpoisoned oats		Poisoned oats	
	No oil	Corn oil	No oil	Corn oil
Number of days exposed......................	6	6	6	6
Number of paired stations...................	25	25	23	23
Total oats eaten (grams).....................	2015.1	3014.2	430.9	561.3
Difference (grams)	......	+999.1	......	+130.4
Difference (%)	......	+49.6	......	+30.3
Avg. consumption per station for period (grams)	80.6	120.6	18.7	24.4
Avg. consumption per station per day (6 days— grams)	13.4	20.1	......	......
Significance of difference	......	Very high	......	Favorable to high
Odds by Student's Method....................	......	9999 to 1	......	32 to 1

Again corn oil was significantly superior over no oil. In this test, when corn oil was applied to unpoisoned oats it was almost 50 per cent better, and when applied to poisoned oats was 30 per cent better than no oil. A station-to-station comparison of 25 pairs during the baiting period showed that 23 favored corn oil and 2 favored no oil; during the poisoning period out of 23 pairs, 13 favored corn oil and 6 favored no oil with 4 even.

TABLE XVIII

CORN OIL VERSUS NO OIL

(EXPERIMENT 35, SECTION C, WAIPIO SUBSTATION)

	Unpoisoned oats		Poisoned oats	
	No oil	Corn oil	No oil	Corn oil
Number of days exposed......................	6	6	3	3
Number of paired stations...................	66	66	55	55
Total oats eaten (grams).....................	2627.5	4706.1	425.3	641.8
Difference (grams)	......	+2078.6	......	+216.5
Difference (%)	......	+79.1	......	+50.9
Avg. consumption per station for period (grams)	36.4	71.3	7.7	11.7
Avg. consumption per station per day (6 days— grams)	6.1	11.9	......	......
Significance of difference	......	High	......	Favorable to high
Odds by Student's Method....................	......	Over 2000 to 1	......	Over 45 to 1

This final test located in a dry area with a low rat population also gave significant gains resulting from the use of corn oil. The amount of gain favoring the oiled oats ranged from 70 per cent when used on the unpoisoned oats to 51 per cent when used on the poisoned oats.

A station-to-station comparison of 66 pairs during the baiting period indicated that 50 favored corn oil, 14 favored no-oil and 2 were even. From 55 pairs meas-

ured during the poisoning period, 33 favored the corn oil, 18 favored no-oil and 4 were even.

TABLE XIX

SUMMARY OF THE THREE SECTIONS (A, B, AND C) OF THE TEST SHOWING THE PERCENTAGE GAINS FOR CORN OIL OVER NO-OIL

Expt. no.	Location	Unpoisoned oats			Poisoned oats		
		No. of pairs	% gain for corn oil	Significance	No. of pairs	% gain for corn oil	Significance
35-A	Kailua	65	59.1	Very high	37	81.0	Very high
35-B	Kailua	25	49.6	Very high	23	30.3	High
35-C	Waipio	66	79.1	Very high	55	50.9	Favorable to high

These tests conducted in three separate locations demonstrated conclusively that rats preferred corn oil-treated oats over plain unoiled oats. The amount of this preference for the treated oats varied from 30 to 80 per cent over unoiled oats. Some of these data are illustrated in Fig. 47.

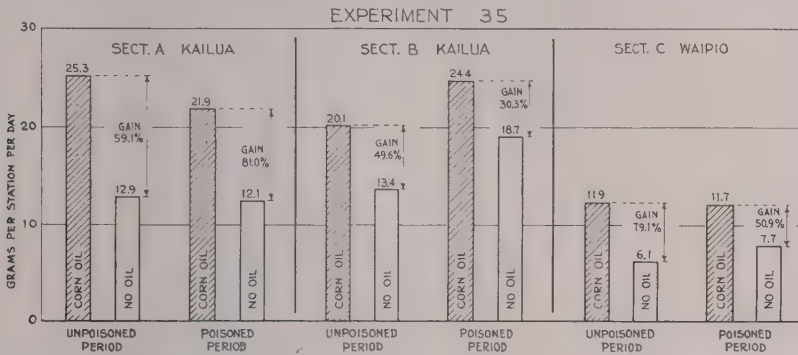

Fig. 47. Graphic presentation of the average daily consumption, in grams, per active station of corn oil treated rolled oats, and unoiled rolled oats, first as unpoisoned and later as poisoned oats (from Tables XVI, XVII, and XVIII).

Corn Oil vs. Raw Linseed Oil: Experiment 36 (Kailua Substation) was conducted to compare raw linseed oil with crude corn oil on oats as a rat attractant. The procedure in this test was identical with that used in Experiment 35 previously described and the same concentration of thallium (1–200) was used in the poisoned grain.

The detailed consumption data have been summarized in the following table:

TABLE XX
CORN OIL VERSUS RAW LINSEED OIL
(EXPERIMENT 36, KAILUA SUBSTATION)

	Unpoisoned oats		Poisoned oats	
	Raw linseed oil	Corn oil	Raw linseed oil	Corn oil
Number of days exposed	6	6	4	4
Number of paired stations	66	66	66	66
Total oats eaten (grams)	6945.8	9269.3	969.6	1320.0
Difference (grams)	......	+2323.6	......	+360.4
Difference (%)	......	+33.5	......	+36.1
Avg. consumption per station for period (grams)	105.2	140.5	14.7	20.0
Avg. consumption per station per day (6 days—grams)	17.5	23.4	......	......
Significance of difference	......	Very high	......	High
Odds by Student's Method	......	Over 10,000 to 1	......	Over 280 to 1

These results show a definite and reliable superiority for the corn oil over the raw linseed oil when applied to rolled oats as an attractant to rats in feeding stations. The amount of this gain ranged from 33 to 36 per cent (see Fig. 48).

PROJECT A-108   EXPERIMENT 36
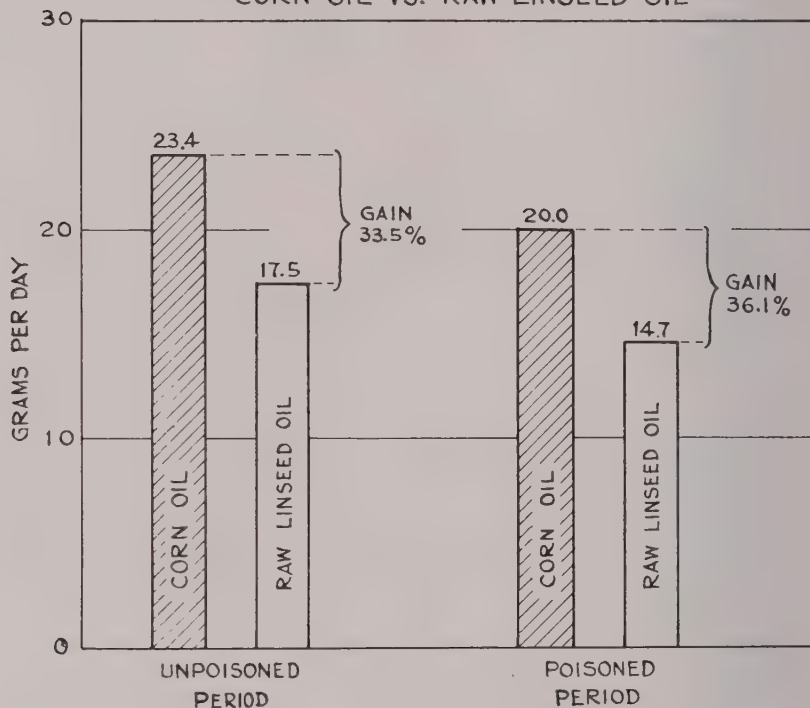### CORN OIL VS. RAW LINSEED OIL

Fig. 48. Graphic presentation of the average daily consumption of rolled oats in grams, per active station, which had been treated with raw linseed oil, and crude corn oil, first during the unpoisoned period and later during the poisoned period (from Table XX).

A station-to-station comparison of 66 pairs indicated that during the baiting period 51 favored corn oil, 13 favored raw linseed oil, and 2 were even; during the poisoning period 46 favored the corn oil, 14 favored the raw linseed oil, with 6 even.

These results tend to support the conclusion that raw linseed oil, while being a good attractant, is not especially appetizing and adds little or nothing to an already good food.

Corn oil, on the contrary, appears to be both an attractant and an appetizer when used in any reasonable concentration.

Corn Oil vs. White Mineral Oil: With the limitation and higher prices of vegetable oils due to the war, it became expedient to investigate possible oil substitutes for use in the rat-control program. Also the development of acidity in some vegetable oils, when mixed with rolled oats (notably crude coconut oil and raw linseed oil) making them unsuited for use with zinc phosphide, further stimulated the investigation of white neutral mineral oil which would remain stable.

Accordingly a test (Experiment 53, April 1943) was conducted in the fields of

Kaeleku Sugar Company to determine the comparative value of a white mineral oil*
with corn oil as rat appetizers. The word "appetizer" alone is used in this test be-
cause the relative attractant power of corn oil and mineral oil could not be deter-
mined in this plan having the two kinds of oil in immediately adjacent pans. To
determine relative value of the drawing or attractant power of the two kinds of oil
requires another separate field test in which the two kinds of oils must be separated
in individual pans spaced some distance apart (15–20 feet). A much larger num-
ber of paired comparisons of this type are required to overcome the chance varia-
tions which will occur due to the varying density of the rat population throughout
any area.

Regular feeding stations were grouped in pairs along a forest trail and cane field
edge and spaced approximately 60 feet apart with the individual stations of each
pair immediately adjacent. Unpoisoned oats were placed in the stations for six
days, followed by three days of poisoned oats. Both corn oil and white mineral oil
were mixed into the rolled oats at the rate of one quart to 25 pounds (40 cc. per
pound). The poisoned oats were prepared by first stirring the zinc phosphide into
the oil and then the mixture added and stirred into the oats.† The concentration of
zinc phosphide was 1–200.

The detailed consumption data were tabulated and summarized. Only the sum-
marized data are presented in Table XXI and Fig. 49.

TABLE XXI

CORN OIL VERSUS WHITE MINERAL OIL
(EXPERIMENT 53, KAELEKU SUGAR CO.)

| | Unpoisoned oats | | Poisoned oats | |
	Corn oil	Mineral oil	Corn oil	Mineral oil
Number of days exposed................	6	6	3	3
Number of paired stations.............	48	48	48	48
Total oats eaten (grams).............	8088.8	9064.0	1213.4	1253.1
Difference (grams)	......	+975.2	......	+39.7
Difference (%)	......	+12.1	......	+3.3
Significance of difference	......	None	......	None
Odds by Student's Method.............	......	12:1	......	......

The results of this prebaited test indicate that we have found an excellent sub-
stitute for our standard corn oil, which is now unavailable.

The slight superiority of white mineral oil over corn oil is without statistical
significance. A station-to-station comparison of 48 pairs indicated that during the
baiting period 14 favored corn oil, 28 favored white mineral oil, and 6 were even;
during the poisoning period 17 favored the corn oil, 20 favored the mineral oil with
11 even. While we have not proved white mineral oil to be better than the standard
corn oil, it is conservative to state that white mineral oil was equal to corn oil in
this test. This is all that we could reasonably hope for.

To date, we have not been able to separate and evaluate the attractive quality or
drawing power of corn oil from its purely appetizing qualities. If it should develop

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*A white mineral oil (Standard Oil Co. No. 9) having approximately the same viscosity as
corn oil was used in this test. It was much cheaper than corn oil.
†See heading entitled "Zinc Phosphide" for detailed data on the preparation of zinc-treated
oats.

that the aroma of the corn oil is necessary to enable the rats to locate the stations promptly, small amounts of the available supply of corn oil could be mixed with the white mineral oil to increase its usefulness. It is highly improbable that white mineral oil could be substituted successfully for corn oil when applied on the old type of individual torpedo baits. Since white mineral oil has no distinctive odor to aid the rats in locating the individual food parcels, it might be but little better than pure paraffin for this purpose.
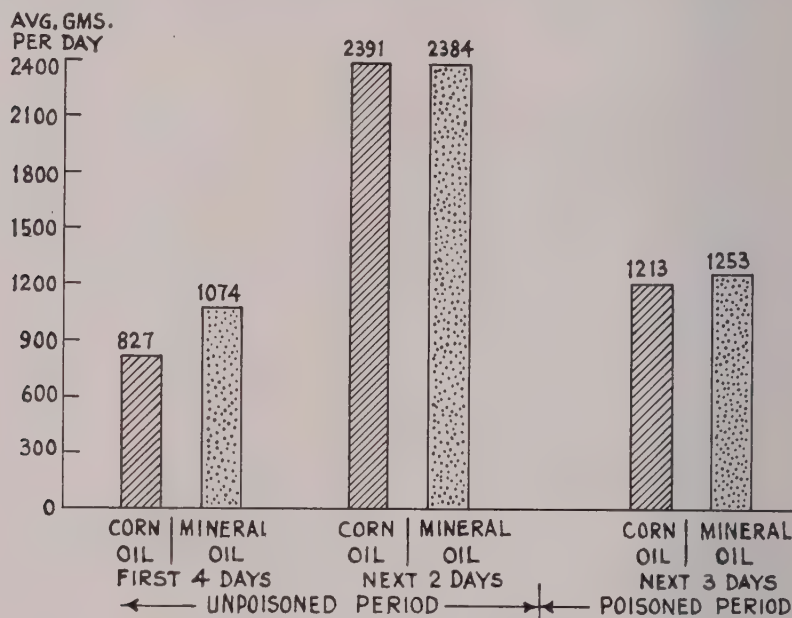

Fig. 49. Graphic presentation of the average total amounts, in grams, of zinc-treated oats consumed per day by rats at forty-eight pairs of feeding stations comparing corn oil with white mineral oil as attractants (from Table XXI).

USE OF COLORING AGENTS TO IDENTIFY POISONED BAITS:

Review of the Literature: The use of some coloring agent to distinguish easily poisoned bait from that which is not poisoned is very desirable, particularly from the standpoint of preventing accidents.

Hovell (40, p. 140) gives some rat-poison formulas common in England showing the inclusion of Prussian blue* as a poison-identifying agent. He comments that, " . . . rats take poisoned food coloured with Prussian blue, lamp black or chrome green almost, if not quite, as readily as they take the same mixture uncolored. . . ."

The National Rat Campaign† (England) reports that, " . . . a special grade of arsenic of necessary degree of purity to insure its effectiveness as a bait and the minute particle size necessary for toxicity. It is colored in accordance with the

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*Formula given by Hovell (40, p. 145):
Arsenic, 1 oz.; Prussian blue, 5 gr.; fine oatmeal to make, 1 lb.
†Chemical Trade Journal and Chemical Engineer, Vol. 113, p. 134, 1943.

poison rules (coloring) 1936, with a water soluble dye (Chlorazol blue) which does not affect palatability with respect to rats."

The 1939 meeting of the National Association of Insecticides and Disinfectant Manufacturers, Inc., held in Washington, D. C., December 1939, adopted a report recommending the creation of standard colors for certain economic poisons. In this connection Cox writes (12, p. 125): "Bulletin No. 25, February 11, 1941, of the Association reports federal specifications for sodium fluoride . . . which provides that 'sodium fluoride for use as an insecticide shall be colored nile blue.'. . . In California insecticide manufacturers voluntarily have distinctively colored powdered fluorine and arsenic compounds, . . . The color selected for sodium fluoride is nile blue and that for lead arsenates and calcium arsenate is pink." No standard has, as yet, been established for thallium, although in the past poisoned baits for rats and mice have been colored various hues by some manufacturers.

Spencer (81, p. 12) reported a laboratory cage trial of grain and color preference that indicated some preference "for red, blue, and green" in that order. "A similar grain and color preference trial in the field showed . . . no decided order of color attraction, . . ."

Experimental: Upon an inquiry from Kaeleku Sugar Company on the subject of coloring poisoned oats, Experiment No. 46 was inaugurated with the following objectives: (1) the selection of a number of suitable coloring agents for use in oat baits, and (2) to determine if oat baits colored with these selected agents are discriminated against by field rats in favor of uncolored oats.

Laboratory Work: A list of the readily available standard dyes was made. D. M. Weller kindly prepared one per cent solutions of the most promising dyes in water, corn oil, and coconut oil. The selected dyes were further diluted to 0.1 per cent solutions and used at the rate of 40 cc. per pound of dry oats. Each solution was sprayed on the oats while they were being stirred. The moistened colored oats were then dried by artificial heat.

Table XXII gives the detailed tabulations of the colors tried out in the laboratory.

TABLE XXII

SOME CHARACTERISTICS OF 14 DYES UNDER TEST FOR COLORING RAT BAITS

Name of dye	Soluble in water—1% or 0.1%	Soluble in corn oil or coconut oil— 1% or 0.1%	Value for coloring oats	Remarks
Ponceau 3 R (red)	Yes	No	Inferior	Too pale at 0.1%
Sudan III (red)	No	Yes	Good in oil only	Very intense at 1%, rather pale at 0.1%
Sudan IV (red)	No	Yes	Good in oil only	Very intense at 1%, rather pale at 0.1%
Bismarckbraun (brown)	Yes	No	Poor	Not bright enough at 0.1%
Neutral red	Yes	No	Good	Better than Congo red at 0.1%
Congo Red	Yes	No	Inferior	Too pale at 0.1%
Methyl Violet	Yes	No	Excellent	Very intense color at 0.1%. Believe further dilution advisable
Methylene blue	Yes	No	Excellent	One of the best—excellent in 0.1%
Iodine green	Yes	No	Good	Slightly inferior to malachite green
Malachite green	Yes	No	Excellent	Best of the green colors. Second best only to methylene blue
Erythrosin (red)	Yes	No	Inferior	Very similar to Ponceau 3 red
Eosin, bluish (red)	Yes	No	Poor	Much too pale
Light green SF (yellowish-green)	Yes	No	Inferior	Too pale a color at 0.1%
Fast green FCF	Yes	No	Excellent	Very close to malachite green

The most promising dyes that were selected from this table for field testing are listed below in their relative order of color intensity.

Water-soluble dyes:
1. Methyl violet
2. Methylene blue
3. Malachite green
4. Fast green

Oil-soluble dyes:
1. Sudan III (red)
2. Sudan IV (red)

Methyl violet in 0.1 per cent solution using 40 cc. per pound of oats gives a very intense color to the grain so a further dilution was recommended. The other dyes listed above were satisfactory in 0.1 per cent solutions. Only a small per cent (5 to 10) of the poisoned grain needs to be colored to distinguish it readily from unpoisoned oats. Sudan III and Sudan IV are the only colors tested which are soluble in oil and therefore usable directly in corn oil or coconut oil.

Field Work: The preliminary field testing consisted in the placing of oats dyed with the selected colors alternating with uncolored oats in pans. The pans were first grouped four to six pans in one location. Each color selected in this preliminary test was then subjected to a separate study in paired pans. In the final test, one pan of each pair contained colored and the other uncolored oats.

The detailed consumption by station pairs (color vs. no color) is summarized in Table XXIII and graphically presented in Fig. 50.

Methylene blue showed a gain of 29 per cent with favorable statistical significance for this gain. This gain is more than mere chance though we cannot account for it. Perhaps the methylene blue has some taste which is pleasing to the rat.

Malachite green also shows a gain of 25 per cent but with low significance in the difference.

Sudan III, Sudan IV, methyl violet and fast green gave from almost identical results to small differences compared with their no-color checks. These were entirely due to chance.

From these results it appears that color in rolled oats is not discriminated against
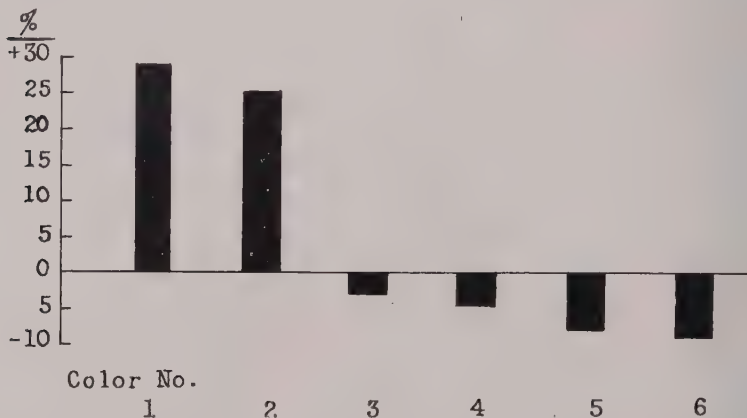

Fig. 50. Percentage of gain or loss in consumption due to the coloring of oats with various dyes (from Table XXIII).

Key: 1—Methylene blue   3—Sudan III   5—Methyl violet
      2—Malachite green   4—Sudan IV   6—Fast green

by rats in favor of uncolored oats. The rats' color sense does not appear to be highly developed. This might well be expected in view of their habit of feeding almost exclusively at night. There is some evidence that methylene blue is actually sought after. There may be some flavor or taste that is attractive rather than the color. Further tests will have to be repeated under varied conditions to establish definitely a superiority for methylene blue.

TABLE XXIII

SUMMARY OF TEST COMPARING COLORED OATS WITH UNCOLORED OATS

	Methyl violet	No color	Methylene blue	No color	Malachite green	No color	Fast green	No color	Sudan III	No color	Sudan IV	No color
Number of paired readings	20	20	27	27	20	20	15	15	37	37	45	45
Oats eaten (grams)	1408	1529	1241	962	1260	1005	1472	1504	2371	2441	3057	3198
Total difference (grams) .	....	121	279	....	255	....	....	132	....	70	....	141
Total difference (%)	....	7.9	29	....	25.4	....	....	8.8	....	2.9	....	4.4
Avg. consumption per reading (grams)	70.4	76.4	46.0	35.6	63.0	50.2	98.1	100.2	64.1	66.0	67.9	71.1
Avg. difference per reading (grams)	....	6.0	10.4	....	12.8	....	....	2.1	....	1.9	....	3.2
Significance of difference .	....	None	Fav.	....	Low	....	....	None	....	None	....	None
Odds by Student's Method	....	4:1	57:1	....	12:1	....	....	2:1	....	2:1	....	2.4:1

COMPARATIVE EFFICIENCY OF SEVERAL RAT POISONS:

Some general information and the results of specific experiments conducted with a number of well-known rat poisons are presented in this section. Some of these poisons might prove suitable for use in the prebaited feeding-station method of field-rat control.

Thallium Sulphate: Thallium sulphate is one of the most toxic of the poisons used for rats. It is slow acting but certain to kill even in relatively low concentrations. It is absolutely odorless and more nearly tasteless than any other rat poison, but it is dangerous to handle because it is readily absorbed through the skin. Thallium sulphate is an ideal poison for use with dry cereal baits, and has been our standard field poison since the work of Barnum (6, pp. 435–442) established its reliability and superiority over other available poisons. For more details about thallium sulphate the reader is referred to U.S.D.A. Technical Bulletin 238 (56).

Cage Studies: Several series of cage tests were carried out using thallium sulphate as the standard lethal agent by which other poisons might be evaluated. In all cage studies reported in this paper, the consumption records were secured on individual rats in separate cages. Water and pieces of sugar cane were offered at all times, whether the rolled oats bait was unpoisoned or poisoned. It was hoped that the results of these cage tests might be used as indexes of what could be expected in the field. The average amount of unpoisoned oats eaten in 24 hours has been expressed in terms of per cent of body weight. The amounts of each kind of poisoned grain may be compared with this basic figure, thus securing some interesting comparative data on acceptance and toxicity.

The results of the cage tests have been summarized and the more basic figures given in Table XXIV. These figures were used as the standard when comparing other rat poisons as possible substitutes for thallium.

The average consumption of unpoisoned oats by rats was $8.6 \mp .3$ per cent of their body weight per day. Subsequently, the rats were induced to eat $4.2 \mp .2$ per cent of their body weight of thallium-poisoned oats which was 50.7 ∓ 2.5 per cent of the average of unpoisoned oats eaten per day. Accepting the standard of 30 mgs. per kilo of body weight as the minimum lethal dose of thallium, the amount of thallium-poisoned oats consumed contained 6 to 8 times the minimum lethal dose (M.L.D.). This ratio of poisoned oats eaten to M.L.D. is presented on the last line of Fig. 51.

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TABLE XXIV

SUMMARY OF CAGE TESTS USING THALLIUM SULPHATE IN
ROLLED OATS (1–200)

</div>

| | Rat species | No. of trials | No. of rats | Avg. body wt. grams | Unpoisoned oats eaten | | |
					No. of days record	Daily avg. grams	% of body weight
(1)	*R. norvegicus*	31	31	195.0	14.2	14.6	$7.6 \mp .2$
(2)	*R. r. rattus*	14	14	109.4	24.6	9.1	$8.6 \mp .4$
(3)	*R. r. alexandrinus*	14	13	82.7	13.7	8.6	$10.8 \mp .6$
	Totals	59	58	148.0	16.6	11.9	$8.6 \mp .3$

| | Poisoned oats eaten in 3 days | | | | |
	Average grams	% of body weight	% of daily avg. unpoisoned	Average hours until deaths	Deaths
(1)	7.3	$3.8 \mp .2$	51.8 ∓ 3.6	40.5	31
(2)	4.7	$4.3 \mp .4$	50.2 ∓ 4.4	32	14
(3)	4.3	$5.1 \mp .5$	48.6 ∓ 5.3	31	12
Totals	6.0	$4.2 \mp .2$	50.7 ∓ 2.5	36.5	57

Out of 59 trials on 58 rats there were 57 deaths with one rat refusing poisoned oats on two occasions. This gives an efficiency rating of 96.6 per cent deaths and 3.4 per cent refusals. The rat which refused the bait had apparently learned to detect poisons because he had survived six attempts to poison him with Rat Nip, L-Tox and red-squill powder. The average number of hours that elapsed from the eating of the poison until death occurred was approximately 36 hours.
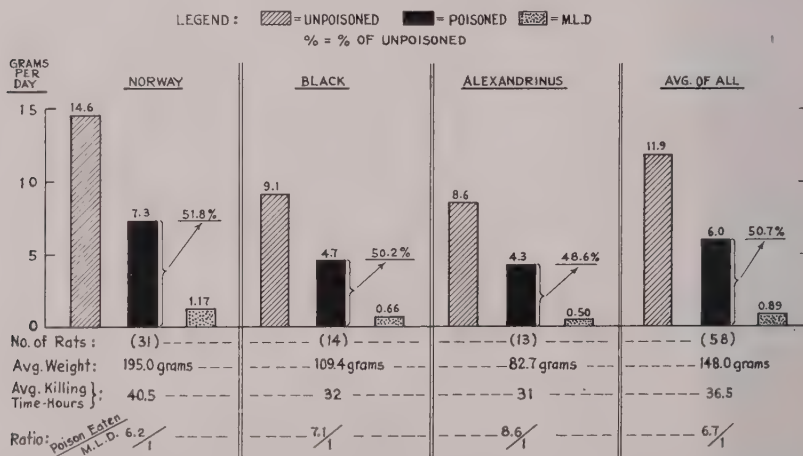

Fig. 51. Graphic presentation of the average grams of oats eaten per day by caged rats. Unpoisoned oats vs. thallium poisoned oats (1–200) (from Table XXIV). Minimum lethal dose from Table II.

Barium Carbonate: Barium carbonate (precipitated) is a widely used rat poison, second only to red squill in popularity. It is a heavy, white, mineral salt, said to be odorless and tasteless. While only mildly poisonous, still it is fatal to dogs, cats, chickens, and even larger animals if eaten in sufficient quantity. Silver and Garlough (77, p. 6) recommend it wherever it can be used with safety, stating that it is "slow in action, and inexpensive," but "effective and dependable when properly set out." Barium carbonate can be mixed with a wide variety of baits and is most acceptable to rats when moistened to a consistency of soft mush. For general poisoning operations Silver and Garlough (77, p. 7) recommend that:

A variety of baits used separately gives the rat a choice of foods and increases the chances of the bait being taken. Baits should be fresh and of good quality. One kind of each of the following classes of food mixed separately with barium carbonate is recommended:

Cereals, as fresh bread, finely ground dried bread crumbs, jelly roll, breakfast cereals, corn meal, and rolled oats moistened with a vegetable or nut oil, using 1 ounce of oil to 1 pound of cereal.

Meats or fish, as hamburger, halibut, salmon, or mackerel, or desiccated egg.

Fruits and vegetables, as apples, melons, tomatoes, carrots, avocados, and bananas.

The powdered barium carbonate should be thoroughly worked into the soft cereal or ground meat with the hands or with a spoon, in the proportion of 1 part of the poison to 5 of the selected food. Water or a vegetable oil should be added when necessary to make the baits moist. . . .

Barium carbonate should be sifted over sliced fruit and vegetable baits and rubbed well into them with a knife. The slices should be moistened, if necessary, should be thin, and must be poisoned in the 1 to 5 ratio as nearly as possible.

Field Poisoning With Barium Carbonate: The early use of barium carbonate in Hawaii, when it was mixed with flour, middlings or rolled oats, has been reviewed under the heading, "Control by Poisoning—History of Poison Work in Hawaii."

The experiment herewith reported (Experiment No. 38, Nov. 1939) was conducted to determine the acceptance of barium carbonate as compared with thallium sulphate when used as a rat poison in rolled oats in the prebaited feeding-station system.

The stations were grouped in pairs 50–80 feet apart with the individual stations of each pair immediately adjacent to each other. During the six-day baiting period the pans of both stations of each pair were filled with identical, unpoisoned, corn-oiled oats. When the bait in the pans was changed, thallium-poisoned oats were placed in the even-numbered pans of each pair and barium-poisoned oats placed in the odd-numbered pans. The poisoned-bait consumption was measured after three days and again four days later. The poisoned oats were then removed from the field. One pan of each pair was left in the field for four more days, and filled with unpoisoned oats. This was done to determine the extent of refusal, if any, of the poisoned oats.

Thallium sulphate was used at the rate of 1 pound to 200 pounds of rolled oats. Barium carbonate* was used at the rate of 1 pound to 4 pounds of rolled oats, mixed dry and then oiled. There was good adherence of the fine precipitated barium carbonate to the rolled oats with no sifting of the poison to the bottom of the container. When corn oil was added, the mixture tended to become pasty and therefore difficult

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*Circular Bulletin No. 167 (1939) (p. 16) Michigan State College recommends 1 to 4.

to measure by volume accurately.   After aging for three days the mixture handled satisfactorily.

The detailed results are summarized and presented in Table XXV and illustrated in Figs. 52 and 53.

TABLE XXV

SUMMARY OF RESULTS COMPARING BARIUM CARBONATE AND THALLIUM SUL-
PHATE AS LETHAL AGENTS IN ROLLED OATS USING THE PREBAITED FEED-
ING-STATION SYSTEM

| | Unpoisoned | | Poisoned | |
	Odd nos.	Even nos.	Odd nos. barium	Even nos. thallium
Number of days	6	6	3	3
Number of paired stations	32	32	32	32
Total oats eaten (grams)	4118.5	3944.2	141.7	291.4
Difference (grams)	+174.3	......	......	+149.7
Difference (%)	+4.4	......	......	+105.6
Avg. consumption per station for period (grams)	128.7	123.3	4.4	9.11
Avg. consumption per station per day (grams)	21.4	20.6	......	......
Significance of difference	None	......	......	Very high
Odds by Student's Method	......	......	......	4500:1
Ratio: poisoned to unpoisoned oats	......	......	1:29	1:13.5

During the unpoisoned check period, the total consumption of all of the odd-numbered stations was 4.4 per cent higher than the even-numbered stations.   A station-to-station comparison of 32 pairs during this period indicated 10 favoring the odd-numbered stations, 8 favoring the even-numbered stations and 14 even. This represents pure chance variation that occurred in the field.

The barium-poisoned bait was poorly accepted.   The ratio of poisoned to unpoisoned oats was 1 to 29 thus showing a high percentage of refusals or at least
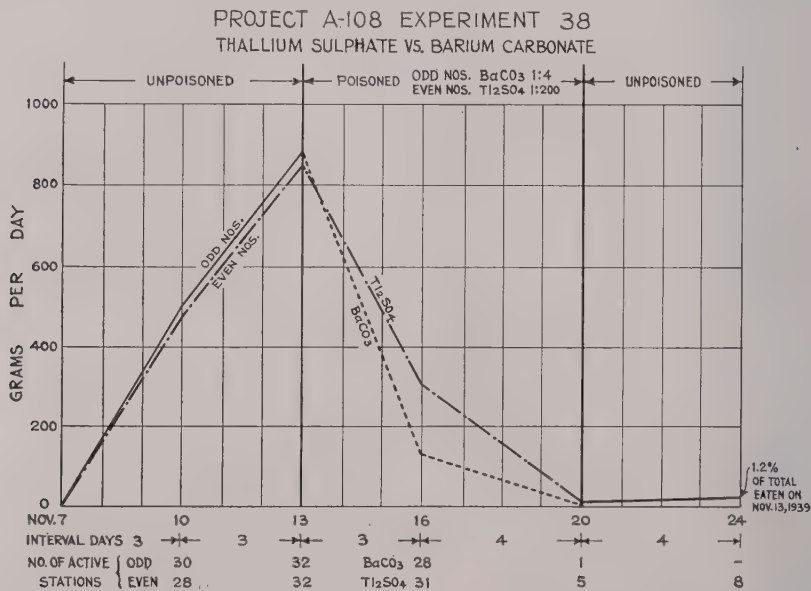

Fig. 52.   The average daily total consumption, in grams, of barium-poisoned oats compared with thallium-poisoned oats, from thirty-two pairs of feeding stations (from Experiment 38).

definite discrimination. The bait treated with thallium sulphate was accepted some-
what better although a ratio of 1 to 13.5 was still poor. The cause of this poor
acceptance has not been definitely determined, but the theory might be advanced
that the rats detected such an abrupt change in the quality of their usual food when
barium carbonate was added that they became suspicious of both baits.

Both treatments of poisoned oats were allowed to remain in the field an extra
period of four days. The consumption of barium-poisoned bait during this period
was nil, and very small (total of 10.2 grams) from five stations containing thallium
sulphate. Only five stations out of 32 showed any activity during the extra four-
day period.

Out of 32 station-to-station comparisons, barium carbonate was better 5 times
and thallium sulphate was better 19 times with 8 pairs even. Thallium sulphate was
more than twice (105.6%) as acceptable as barium carbonate under the conditions
of this test.

When unpoisoned grain was returned to the even-numbered pans for four days,
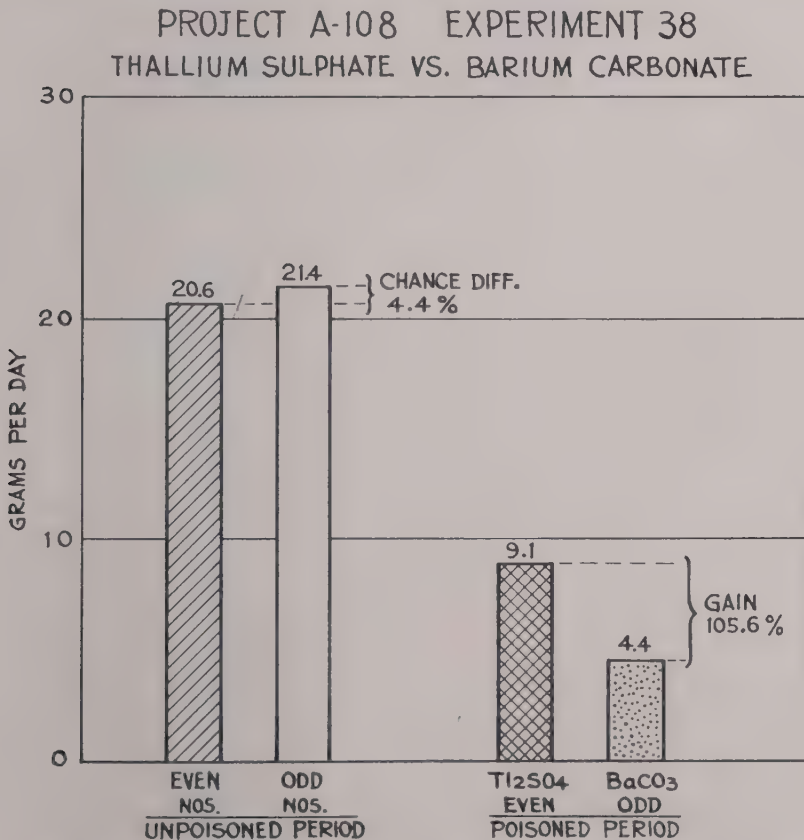very little activity developed, only an average total of 21 grams was consumed daily

Fig. 53. Graphic presentation of the average daily consumption, in grams, per active sta-
tion of barium-poisoned oats compared with thallium-poisoned oats, from thirty-two pairs of
feeding stations (from Table XXV).

from eight stations (mostly from five stations). This amount was but 1.2 per cent of the total of unpoisoned grain eaten daily just before poisoned bait was put out. This indicates a very small return consumption. Either some rats became definitely bait shy and stayed away or all had eaten enough of either barium carbonate or thallium sulphate to result in death.

These results show a definite and reliable superiority of thallium sulphate over barium carbonate as a rat poison when added to rolled oats and used in the prebaiting method of field-rat control.

Arsenic: Arsenic is not a serious competitor of thallium sulphate or of zinc phosphide as a poison for rats in Hawaii, but it has been used as a second choice for thallium sulphate when the thallium was not available, and before zinc phosphide had been thoroughly tested.

Arsenic is poisonous to all animals although it is less toxic than strychnine, thallium sulphate, or zinc phosphide. Arsenic is generally accepted to be both odorless and tasteless, although we have doubts about it being absolutely tasteless to rats. Only the best grade of finely ground arsenic should be used as a rat poison, and the usually recommended concentration in rat bait is five per cent by weight. Eskey (28, p. 70) used as much as ten per cent arsenic in rat bait for plague work on the island of Maui, because, as he stated (p. 64), "The presence of arsenic in food was quickly detected by rats, so that when it was used in small percentages the efficiency was greatly reduced." We have not had experience with this higher concentration as we have adhered to the recommended five per cent arsenic in our cage tests.

We believe that arsenic is more acceptable when mixed in wet baits particularly those containing fish or animal products. Hamilton (38, p. 15) has suggested the formula:

> "Arsenic: 2 ounces
> Salmon: 1 can*
> Corn meal: 1 pound"

Hamilton also states that, "Arsenic lightly dusted on buttered bread has proved efficacious on many occasions" and again, "A level tablespoonful of powdered arsenic thoroughly mixed with a pound of cottage cheese is an efficient raticide. . . . " However, in our field-control work in Hawaii wet baits would be too expensive and difficult to distribute, so we have continued to use dry cereals as the basis of all rat baits.

Cage Tests Using Arsenic: Two forms of arsenic were used in the cage tests— the insoluble oxide (As_2O_3) and the water-soluble pentoxide (As_2O_5). It had been suggested that a soluble form might be less objectionable to rats on the assumption that the gritty texture of the insoluble form might adversely influence acceptance. In these cage tests, however, the soluble form (pentoxide) did not appear to be any more acceptable than the insoluble form. Neither of these forms killed many rats, and both appeared to be readily detected. Arsenic trioxide (insoluble) ground finely enough to pass through a 200-mesh screen was not more acceptable than normal arsenic although it was more toxic. Spencer (78, p. 8) states that, "Compared with standard 100 mesh, chemically pure, arsenic trioxide, a sample that has been pulverized to diameters of 1 to 3 microns exhibits five times the usual toxicity."

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*A can containing approximately 15 ounces.

From his experience in the taste testing of arsenicals, Dr. F. E. Hance, chemist of the Experiment Station, H.S.P.A. has stated that arsenic immediately causes a reaction in the salivary glands not unlike that caused by vinegar in the salivary glands of a patient with mumps. If arsenic affects rats in a similar manner, many rats must detect the poison almost immediately and then refuse to eat the poisoned bait. This might account for the large numbers of total refusals of arsenic baits the world over. In our experimental studies we found that in 17 cases out of 29 trials arsenic-poisoned oats were only touched without evidence of actual eating. In many instances the rats appeared to deliberately spill the arsenic-treated oats. This has happened more frequently with arsenic than with any of the other poisons, and no doubt some small amounts of missing poisoned grain have been credited as eaten by rats which were actually total abstainers. There were seven positive refusals where all poisoned grain remained in the feeding pans. Out of 29 trials only five deaths resulted, one of which was from causes other than arsenic poisoning. The average consumption of arsenic-poisoned oats per fatally poisoned rat was 1.12 grams or 0.9 per cent of its body weight (126.6 gms.) and only 10.5 per cent of its average daily consumption of unpoisoned oats. Thus we have definite evidence that large numbers of rats survive poison campaigns in which arsenic is used as the lethal agent.

Strychnine: The use of strychnine as a rat poison in Hawaii has been reviewed earlier in this paper under the subject, "Control by Poisoning—History of Poison Work in Hawaii." It is extremely poisonous, but unfortunately has a bitter taste that must be camouflaged if it is to be accepted by rats.

Pemberton (62, p. 27) found strychnine to be an effective rat poison at Honokaa although he noted that some rats survived large doses. Barnum (6, pp. 427–431) studied the use of strychnine on Kauai where large amounts of whole wheat or rolled barley, poisoned with strychnine, were being used on plantations. During 1928 over 90 tons of strychnine-treated wheat were scattered on the several plantations which were concerned with rat control on that island. Barnum reported that the efficiency of strychnine bait was steadily declining and that better control methods were imperative. He found that thallium sulphate met this need, so strychnine was soon almost forgotten.

Concentrations of Strychnine: The early strychnine formula recommended by Lantz (45, p. 252) carried a concentration of 0.21 per cent of strychnine alkaloid (see strychnine formula No. 8-A in Appendix). Lantz also gives a strychnine sulphate formula (see strychnine formula No. 8-B in Appendix) which would be equivalent to one ounce of strychnine to 15 pounds of rolled oats or about the same percentage as the Fish and Wildlife Service now uses when strychnine is employed. This concentration is almost 0.42 per cent.

F. E. Garlough, Senior Biologist of the Fish and Wildlife Service, in commenting on the use of strychnine in a letter to the writer dated November 15, 1943, has this to say:

You know we do not recommend strychnine for general use in rat baits. In special cases it may be used to advantage.

Of late years, where strychnine has been used, the concentration has been stepped up to about 1 ounce of strychnine alkaloid to 10 or 12 pounds of crushed oats. This has been due to the fact that the Norway rat does not eat a sufficient amount of the poison bait to justify

using such a concentration as weak as 0.25 per cent. We have found that we will kill a larger number of rats by using the stronger concentration of about 0.5 per cent.

Cage Tests Using Strychnine: In preparing baits for the cage tests, the formula for the modified mixture, No. 7 in the Appendix, was used. The concentrations of strychnine were 1–200 and 1–300, which agrees closely with recent work of the Fish and Wildlife Service mentioned before. The summary of this work is given in Table XXVI.

TABLE XXVI

SUMMARY OF CAGE TESTS USING STRYCHNINE IN ROLLED OATS
(1–200 AND 1–300)

| | Rat species | No. of trials | No. of rats | Avg. body wt. grams | Unpoisoned oats eaten | | |
					No. of days record	Daily avg. grams	% of body weight
(1)	R. norvegicus	8	5	212.9	6.6	13.7	6.8
(2)	R. r. rattus	18	6	105.0	7.0	8.7	8.5
(3)	R. r. alexandrinus	11	6	103.2	8.0	8.5	8.2
	Totals	37	17	127.8	7.1	9.6	8.0∓.3

| | Poisoned oats eaten in 3 days | | | |
	Average grams	% of body weight	% of daily avg. unpoisoned	Remarks
(1)	4.5	2.6	38.8	3 deaths—all trials 1–300
(2)	7.6	7.1	93.8	No deaths—11 trials 1–300, 7 trials 1–200
(3)	9.8	9.2	124.1	1 death—1–300, 5 trials—1–200, 3 trials—1–300, 2 trials, bait spilled
Totals	7.5	6.6∓.7	89.1∓12.1	4 deaths

The results obtained by the use of strychnine as a rat poison were very erratic. Only four rats died out of 37 trials on 17 rats. Of the four dead rats three were *R. novegicus* and one was *R. r. alexandrinus*.

The average consumption of strychnine bait (1–300) by the mortally poisoned rats was 2.4 per cent of their body weight while the average consumption for the entire group (including the 4 which died) was 6.6∓.7 per cent.

In 11 trials the rats ate all of the poisoned oats placed in the cages during the three-day interval and none of these died. This accounts for the high per cent consumption of strychnine-poisoned bait compared with the average daily consumption of unpoisoned oats (see Table XXVI). The large amounts of strychnine consumed were actually less fatal than the small amounts.

Red Squill: Red squill is the dried powder obtained from a perennial bulb (*Urginea maritima*) which grows wild along the coast of the Mediterranean Sea. Where there is danger from accidental poisoning of pets and human beings in camps, villages and cities, the only absolutely safe rat poison is *red squill*. All of the effective rat poisons *except red squill* are highly toxic to all animal life and should not be placed where there is any possibility of their being taken by humans or domestic animals. Red squill has an acrid taste which is objectionable to most animals and, if taken in large quantities, it acts as an emetic. Since rats cannot

vomit, this poison becomes almost a specific for them. However, red squill has two serious defects:

(1) Red squill preparations and powders have varied greatly in toxicity with resulting uncertainty in killing power.*

Because of this variability, Munch, Silver and Horn (55, p. 34) recommended that, " . . . squill powder should be tested before being marketed and adjusted so that 10 grams of 10 per cent squill bait will kill a minimum of 1 kilogram of rat. . . ." (One ounce should kill 6¼ pounds of rats.) This recommendation should be carried out by making a bioassay† test of the powdered red squill before using large quantities in the field. Only male rats should be used as test animals as they are twice as resistant to red squill as females; according to Ward *et al* (87, p. 354), this is due to the presence of the male hormone, testosterone.

(2) While rats may not suspect poison from the acrid taste of red squill when they first eat it, the survivors of a red squill-poison campaign are not likely to eat anything containing red squill again.

These facts raise a grave doubt as to the usefulness of red squill on a large field scale. However, several cage and field tests using various forms of red squill were completed and are herewith reported.

Red Squill Powder Compared with Thallium Sulphate in the Same Area: The red squill powder used in these two field tests was purchased from a reputable drug supply house and was part of a lot that was widely used in the Territory before the war. Unfortunately, no bioassay was made, for subsequent cage tests indicated that this lot of red squill was only half as toxic as the standard recommended by the Fish and Wildlife Service. This meant that more bait must be consumed to give satisfactory killing power. However, good results should be expected anyway, because rats normally eat liberal amounts of poisoned bait following a period of baiting.

The first test (Experiment 39, February 1940) compared the acceptance by rats of red squill powder with thallium sulphate when applied to rolled oats under the prebaiting system. The procedure in this test was identical with that described previously for testing barium carbonate (Experiment 38). The stations were grouped in pairs 50–80 feet apart with the individual stations of each pair immediately adjacent.

When the bait was changed, thallium-poisoned oats were placed in the even-numbered pans and red squill-poisoned oats were placed in the odd-numbered pans. The consumption of poisoned oats at all stations was measured after four days. The experiment was then concluded.

Thallium sulphate was used at the rate of one pound to 200 pounds of rolled oats. The red squill powder was mixed with dry rolled oats at the rate of one to 16.‡ then a boiled starch syrup was added and mixed, followed by immediate drying

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*Experimentally, the Fish and Wildlife Service, Dept. of Interior, has produced extracts of red squill of 100 or more times the potency of the original powder. When such fortified squill is available for general use, the ideal rat poison for home use will be at hand.

†Silver & Munch (74, p. 4) have given directions for making a bioassay of red squill.

‡Concentration recommended by Michigan Circular Bulletin No. 167, p. 16, and Farmer's Bulletin No. 1533, p. 7–9, U.S.D.A., 1933.

in an oven at 80° C. This gave a finished bait that was mechanically satisfactory with the red squill tightly adhering to the oat grains. Preliminary trials had shown that red squill, when mixed dry, sifted to the bottom readily. Moistening the grain and red squill mixture with water and redrying by heat did not entirely remedy the difficulty. Some corn oil was used uniformly in all baits before placing in the field.

The "boiled starch syrup" formula mentioned above and used by Barnum (6, p. 428) for thallium-wheat formula contained baking soda. The use of baking soda in the starch formula is a carry-over from the old U.S.D.A. strychnine formula. There was no appreciable or significant difference in the acceptance of a red squill formula containing baking soda compared with one without baking soda. This point was tested in Experiment 40 by segregating the consumption data obtained from the first 19 feeding stations which had received the red squill formula containing baking soda and the remaining 29 stations which had received the red squill formula without the baking soda. A summary of the consumption under the two treatments follows:

Treatment	Unpoisoned oats (grams)	Red squill (grams)	Per cent of red squill to unpoisoned oats
Red squill with baking soda	2,058.2	186	9.04
Red squill without baking soda.....	4,778.7	518.8	10.85
Difference			1.81

The red squill formula without baking soda may be prepared as follows:

Ingredients	Amounts	Procedure
Starch	9 gms.	
Water	350 cc.	Add and boil 15 minutes
Washed sugar	200 gms. plus 75 cc. water	Add, stir and bring to a boil
Glycerine	24 gms.	Stir

Separately, weigh out five pounds (2268 gms.) of rolled oats, add 142 gms. (1–16) of red squill powder and mix dry. Then add the above syrup-starch liquid to the grain and mix evenly. Dry in oven at a temperature of 80° C.

At the conclusion of Experiment 39, the detailed consumption by station pairs was tabulated and summarized in Table XXVII and illustrated in Fig. 54.

TABLE XXVII

SUMMARY OF RESULTS COMPARING RED SQUILL AND THALLIUM SULPHATE AS LETHAL AGENTS IN ROLLED OATS USING THE PREBAITED FEEDING-STATION SYSTEM

	Unpoisoned		Poisoned	
	Odd nos. stations	Even nos. stations	Odd nos. red squill	Even nos. thallium
Number of days	6	6	4	4
Number of paired stations...................	52	52	52	52
Total oats eaten (grams)....................	8805.0	8837.3	248.3	2296.4
Difference (grams)	......	+32.3	......	+2048.1
Difference (%)	......	+.37	......	+825.8
Avg. consumption per station for period (grams)	169.3	169.9	4.8	44.2
Avg. consumption per station per day (grams).	28.2	28.3	......	......
Significance of difference	......	None	......	Extremely high
Ratio: poisoned to unpoisoned oats..........	......	......	1:35.5	1:3.8
Ratio: all poisoned to all unpoisoned oats....			1:6.9	

A station-to-station comparison of 52 pairs during the blank test period indicated 18 favoring the odd-numbered stations, 23 favoring the even-numbered stations with 11 even. Also the total consumption of all of the even-numbered stations averaged .37 per cent higher than the odd-numbered stations. Thus we find that the pure chance variation averaged extremely small in this test.

During the poisoning period all of the 52 paired stations in the test favored thallium sulphate. Under the conditions of this test, where a choice was allowed, thallium sulphate was accepted over eight times better than red squill powder.

The ratio of the consumption of poisoned to the unpoisoned oats was 1 : 35.5 for

PROJECT A-108   EXPERIMENT 39
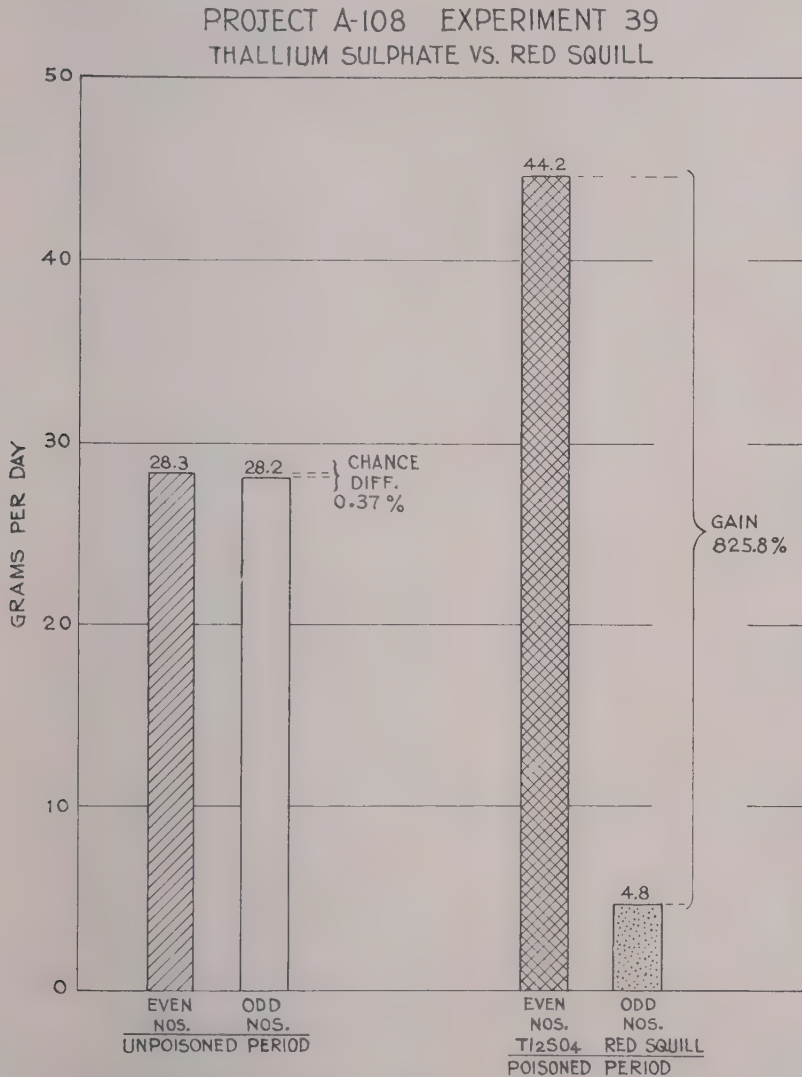THALLIUM SULPHATE VS. RED SQUILL

Fig. 54.   The average daily consumption, in grams, per active station of red squill-poisoned oats compared with thallium-poisoned oats (from Table XXVII).

the red squill, and $1:3.8$ for the thallium sulphate. This strongly indicates that nearly all of the rats coming to the paired stations ate from the thallium pans in preference to the red squill pans. The total poisoned bait consumption was good, the ratio to unpoisoned bait consumed being $1:6.9$ for the entire period. These facts indicated that the rats did not become suspicious of thallium merely because they did not like red squill in the adjacent pan. Red squill was disappointing to the point of being a total failure in this test when compared with thallium sulphate in rolled oats.

Red Squill Powder Compared with Thallium Sulphate in Separate Areas: Since red squill was almost completely refused in favor of thallium sulphate in the first test reported (Experiment 39), it was desirable to determine if red squill would be more acceptable if no other choice were near at hand. Accordingly in this second test (Experiment 40, March 1940), red squill only was used in one area for two periods followed by two periods of thallium sulphate to measure the amount of red squill refusals. The results from this area were compared with thallium sulphate used in a second area adjacent to the first.

The test using red squill was installed at Kailua Substation using 48 regular feeding stations spaced *singly* 50–80 feet apart in big cane and along wastelands. Otherwise the technique in this test was identical with those previously reviewed.

Red squill powder was mixed with dry oats at the rate of 1 to 16 exactly as described in Experiment 39. Thallium sulphate was used at the rate of 1 pound to 200 pounds of oats. Corn oil was used uniformly as the attractant.

The detailed consumption data were tabulated and summarized in Table XXVIII and illustrated in Fig. 55.

TABLE XXVIII

SUMMARIZED DATA OF EXPERIMENT NO. 40 EVALUATING THE KILLING POWER OF RED SQUILL POWDER IN ROLLED OATS FOLLOWED BY THALLIUM SULPHATE AS CHECK

	1st period			2nd period			3rd period			4th period		
	Unpoisoned		Red squill	Unpoisoned		Red squill	Unpoisoned		Thallium	Unpoisoned		Thallium
Interval (days)	4	2	3	4	2	3	4	2	3	4	2	3
No. of active stations...	46	47	47	48	47	43	48	48	48	10	17*	16
Total oats eaten (grams)	3400	3444	704	4979	3872	388	5047	4408	1333	149	295	130
Avg. daily consumption (grams)	850	1722	....	1245	1936	....	1262	2204	....	37	147	....
Consumption—% of highest 2 days	49.4	100	40.9	72.3	112.4	22.5	73.3	128.0	77.4	2.1	8.5	7.6
Consumption—% of highest 2 days	....	....	....	....	....	....	....	100	60.5	1.7	6.7	5.9
Ratio: poisoned to unpoisoned oats		1:9.7			1:22.8			1:7.1			1:3.4	

*Mice present in increasing numbers now that the rats are absent. Mice account for a large part of the increase.

During the first period the consumption of unpoisoned oats during the baiting was quite normal, and was followed by a fair consumption of red squill-poisoned oats (41 per cent of the average of the last two days before the first poisoning). The ratio of the poisoned to unpoisoned oats consumed was 1 to 9.7.

However, on returning to the use of unpoisoned oats during the second period (March 25 to April 6) the consumption increased to a higher level than during the first period (100% to 112%) indicating that the kill due to the first red squill appli-

cation had been *nil,* or at least the replacements by new emigrants had actually increased the total number of clients visiting the stations. This larger population of rats (112%) ate only slightly more than one-half as much red squill-poisoned bait this second period as was eaten during the first exposure (22.5% vs. 41%). Many rats which ate small amounts of red squill the first time refused it entirely on its second appearance. It is also evident that many had not eaten a lethal dose so they became definitely bait shy of red squill. There was strong evidence that these rats visited the red squill pans each of the three nights of exposure, but refused to eat any appreciable quantity of the bait. The bitter taste of red squill is unmistakable and this must be the basis for the selective eating by the rats because the presence of red squill did not keep the rats from visiting the stations and eating unpoisoned oats or even the thallium-poisoned oats during the following periods of the study.

The consumption of unpoisoned oats during the next period (April 6–12) reached a still higher level (128%) over the best consumption before the first red squill poisoning. This indicated that two exposures of red squill had utterly failed to kill the rats that were regularly visiting the stations under study. After these trials with red squill, unpoisoned oats were exposed followed by thallium-poisoned oats from April 12–15. The consumption of thallium-poisoned bait was normal, being 60.5 per cent of the best previous day's consumption of unpoisoned bait, giving further evidence that the rats had no memory of the red squill as far back as six days before to prejudice them against the thallium-poisoned oats. These data support the theory that the decision to eat the bait or to refuse it rests on the taste at the time of eating and not on memory beyond the six days of the last baitings, which were sufficient to establish the habit of eating at the station as before.

The return consumption of unpoisoned oats following the thallium bait was only 6.7 per cent at the end of six days compared with the previous peak of unpoisoned-oats consumption on April 12 which was considered 100 per cent. This would amount to 8.5 per cent compared with 128 per cent when calculated back to the best
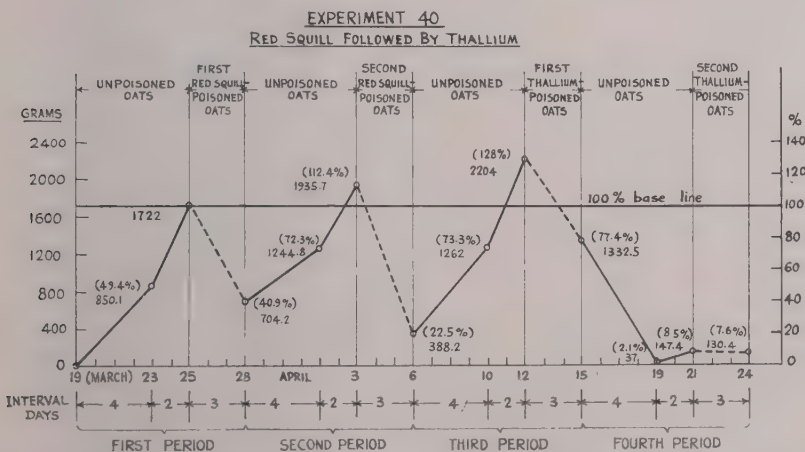

Fig. 55. The average daily total consumption of unpoisoned and red squill-poisoned oats at forty-eight feeding stations for two successive periods, followed by two periods of feeding of unpoisoned and thallium-poisoned oats (from Table XXVIII).

day's consumption before the first red squill application (March 25) as the base of 100 (see Fig. 55). As these stations were laid out in a long line mostly between cane and wasteland, and not in blocks, some reinfestation should be expected to occur in a very short time. Also much of this small consumption following thallium poisoning was due to a few mice which appeared at the pans for the first time. Apparently they were able to eat at the stations in comparative safety, since the rat population had been so drastically reduced.

It should be noted that the total number of active stations (48) remained active throughout the test until after the first thallium application (see Table XXVIII). Following the first thallium poisoning, only 10 stations showed evidence of any activity after four days of exposure of unpoisoned oats, and at the end of six days only seven more stations had been slightly disturbed. The remainder stood six days in the field without being touched by either rats or mice.

Attention should also be called to the ratios of the poisoned to unpoisoned bait consumed during each period (see last line—Table XXVIII). The decidedly poor ratio of 1:22.8 obtained in the second period for red squill indicated a failure to obtain any reasonable acceptance and consumption. In contrast to this, the ratio for the next period using thallium sulphate returned to 1:7.1 which is well within the range of satisfactory acceptance for the standard prebaiting procedure. That the thallium was very effective is conclusively shown by the low consumption of unpoisoned oats in the period immediately following its application (April 15–21). This is in direct contrast to the unpoisoned oats in the periods following the two red squill applications.

In conclusion it will be noted that during the period when red squill was first applied, although acceptance was fair, its killing power was almost zero, as proved by the return consumption of unpoisoned oats. When red squill was exposed for the second time, it was very much less acceptable, amounting to wholesale refusals of the bait.

While this lot of red squill proved to be only half as toxic as the recommended government standard, it was lethal in cage tests when rats could be induced to eat any measurable portion. This small portion was well below the expected consumption of poisoned following unpoisoned bait. Actually many rats refused to eat any appreciable quantity of red squill bait compared with baits containing zinc phosphide or thallium sulphate.

A study of thallium sulphate was carried on during the same period of time as the red squill study for purpose of comparison. The procedures and schedules were originally the same for this study as those used in the red squill area.

This series of stations (34) was operated from March 19 to April 6 only as practically no activity occurred after the first poisoning with thallium sulphate. This test was also installed at Kailua Substation in an immediately adjacent field. The stations in the first group (19) were spaced very close together (30–35 feet) in an area recently poisoned. The remainder of the stations (15) were located in abandoned cane.

The detailed consumption data of the thallium sulphate study were recorded and summarized in Table XXIX and illustrated in Fig. 56.

TABLE XXIX

SUMMARIZED DATA FROM EXPERIMENT NO. 40 EVALUATING THE KILLING POWER OF THALLIUM SULPHATE IN ROLLED OATS

| | First period | | | Second period | | |
	Unpoisoned		Thallium	Unpoisoned		Thallium
Interval (days)	4	2	3	4	2	3
No. of active stations	32	33	33	5	6	3
Total oats eaten (grams).........	1924.4	1450.4	341.3	149.7	73.7	11.3
Avg. daily consumption (grams) ..	481.1	725.2	....	37.4	36.8	....
Consumption—% of highest 2 days	66.3	100	47.1	5.1	5.1	1.6
Ratio: poisoned to unpoisoned oats			1:10.1			

This study was started at the same time as the red squill test and parallels it to April 6, hence the climatic conditions were the same for both tests.

The consumption of unpoisoned and poisoned oats followed the usual pattern expected for thallium sulphate, although the consumption of poisoned oats was perhaps slightly lower than usual, resulting in a somewhat less favorable ratio. This is accounted for by the fact that the first 19 stations were spaced very close in an area only recently poisoned and containing relatively few rats.

The real purpose of this test was to compare in per cent the consumption of unpoisoned grain that would occur after the first thallium application with the consumption of unpoisoned oats following the first red squill application.

We find that the return consumption of unpoisoned oats following thallium poisoning, after six days exposure, was 5.1 per cent compared with the red squill record obtained on the identical dates (April 3) amounting to 112.4 per cent. This is conclusive proof that the climatic conditions could not have been a factor in the differences occurring between the two poisons. The thallium sulphate was effective while the red squill was practically worthless.
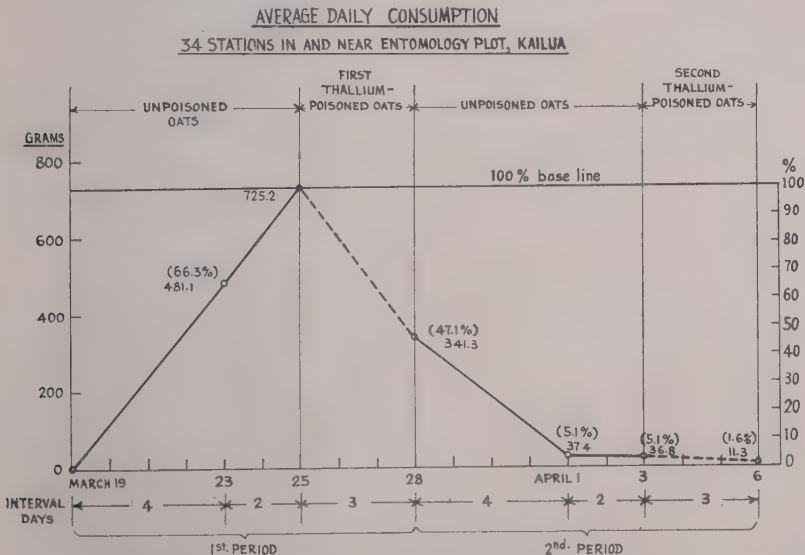

Fig. 56. The average daily total amount of unpoisoned and thallium-poisoned oats eaten by rats at thirty-four feeding stations for two successive periods of treatment (from Table XXIX).

Cage Tests Using Red Squill Powder: The baits used in these tests were rolled oats, bread, and fish scrap treated with red squill powder in concentrations varying from 1 to 5 down to 1 to 15.

Out of 22 trials on 19 rats there were 9 deaths (40.9 per cent), 11 recoveries (50 per cent) and 2 definite refusals (9.1 per cent). The deaths occurred on an average of 20 hours after eating the poisoned bait. The rats in these tests consumed an average of 9.3 per cent of their body weight of unpoisoned bait per day, followed by three per cent of their body weight of red squill-poisoned bait.

The baits containing red squill were not sufficiently attractive to induce many rats to eat enough to obtain a lethal dose. It should be noted that the average amount of the dry squill powder actually eaten by the 9 rats which died was .49 gram and that this amount was just slightly more than double the amount (.22 gram) eaten by the 10 rats which recovered. This lot of red squill powder was evidently below the recommended standard of toxicity since .11 gram of the powder should have been lethal for the average weight (111 grams) of rats used in these tests. Most of the rats refused to accept a lethal dose of the red squill baits, although under the same conditions they would have consumed five to seven times a minimum lethal dose of thallium sulphate. Red squill powder proved to be better than "L-Tox" (discussed in the next test), but was still too poor and uncertain to be used in large-scale rat-control operations.

"L-Tox"*: The Boards of Health of the cities of Oakland and San Francisco strongly recommended a commercial red squill product called "L-Tox" for rat control under their conditions.

We were interested in such a preparation for possible use in the camps and villages of the sugar plantations. Therefore, a field trial (Experiment 41, October 1940), consisting of 35 regular feeding stations placed singly 50–80 feet apart, was installed at Kailua Substation.

The first 15 stations were grouped in and around a field of 17-month-old cane (see Fig. 58-A). The remaining stations were placed in a continuous single line along wasteland and a stream (see Fig. 58-B), which afforded excellent rat harborage. This line of stations formed a corridor "in enemy country." Under these conditions this area was subject to a continuous reinfestation of migratory rats from both sides.

The consumption of oats was measured and recorded for each period of the treatment. The "L-Tox" was weighed into 20-gram lots, one for each station, and placed in the pans at the appropriate time and moistened with a small amount of water to form a thick mash, as directed by the manufacturers of the product. At the end of the "L-Tox" poisoning test the remaining "L-Tox" at each station was collected, numbered for identification, dried, reweighed and recorded in Table XXX. Some loss undoubtedly resulted from the maggot infestation that occurred during the four-day exposure, which is of necessity credited to consumption by rats.

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*"L-Tox" is a commercial red squill rat bait made up of 20 per cent red squill powder mixed with 80 per cent shrimp meal. This product is manufactured by John F. Leinen Chemical Company and distributed by the United States Supply Company, both of 1337 Mission Street, San Francisco, California.

The detailed consumption data were tabulated and summarized in Table XXX and illustrated in Fig. 57.

TABLE XXX
SUMMARIZED DATA EVALUATING THE KILLING POWER OF "L-TOX" FOLLOWED BY THALLIUM SULPHATE IN ROLLED OATS AS CHECK

| | First period | | | Second period | | | Third period | | |
	Unpoisoned		"L-Tox"	Unpoisoned		Thallium	Unpoisoned		Thallium
Interval (days)	4	2	4	4	2	4	4	2	4
No. of active stations	35	35	35	35	35	35	13	20*	22
Total bait eaten (grams).........	3746	3420	261	5669	4805	1803	597	972	380
Avg. daily consumption (grams) ..	937	1710	....	1417	2403	....	149	486	....
Consumption—% of highest 2 days	154.8	100	14.8	82.9	140.5	105.4	7.8	28.4	22.2
Consumption—% of highest 2 days	....	....	....	....	100	75.0	6.2	20.2	15.8
Ratio: poisoned to unpoisoned bait		1:27.5			1:5.8			1:4.1	

*Mice account for a part of the increase.

The area along the stream and wasteland proved to be heavily infested with rats —more than was anticipated. There were many pans empty of unpoisoned oats when the records were taken. Therefore the absolute peak of consumption of unpoisoned oats was not always obtained.

The "L-Tox" made a very poor showing. Using the average consumption of unpoisoned oats on the two preceding nights as 100, the "L-Tox" showed only 14.8 per cent. The ratio of the poisoned bait ("L-Tox") consumed to the total unpoisoned oats consumed was 1 to 27.5, a very unfavorable ratio indicating a high number of partial or total refusals.
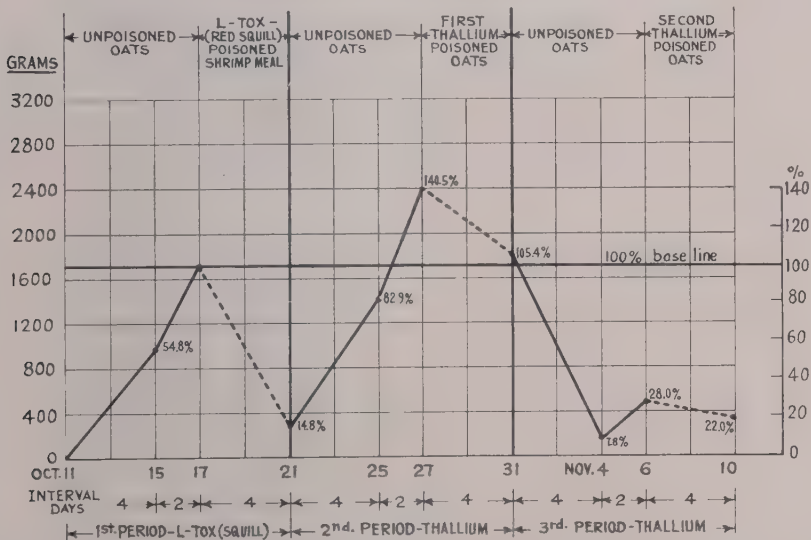

PROJECT A-108   EXPERIMENT 41

Fig. 57. The average daily total amount of unpoisoned oats and L-Tox eaten by rats at thirty-five stations, followed by two successive periods of feeding of unpoisoned and thallium-poisoned oats.

The base line (100%) represents the average of the two best days of consumption before the first attempt was made to poison the rats (from Table XXX).

On returning to the use of unpoisoned oats during the second period, the consumption increased to a higher level than before (140.5 per cent), indicating that the kill due to the "L-Tox" application had been *nil,* or at least the replacements by new migrants had actually increased the total number of clients visiting these stations.

Thallium-treated oats (1–200) were then applied, resulting in more consumption of poisoned oats (105.4 per cent) than unpoisoned oats before the "L-Tox" poisoning. This amounted to 75 per cent as much as the average of the last two nights of unpoisoned grain consumed just previous to the thallium application (see bottom of Table XXX). This was an amount above the average—Experiment 40 was 60.5 per cent. This gives additional evidence that the rats had no memory or prejudice against these stations on account of the "L-Tox" having been in the pans six days previous. As mentioned in the previous test, the six days of unpoisoned oats immediately preceding the thallium poisoning had been sufficient to establish the habit of eating at the station as before. Under these conditions thallium-poisoned oats are always eaten in sufficient quantity to be very effective.
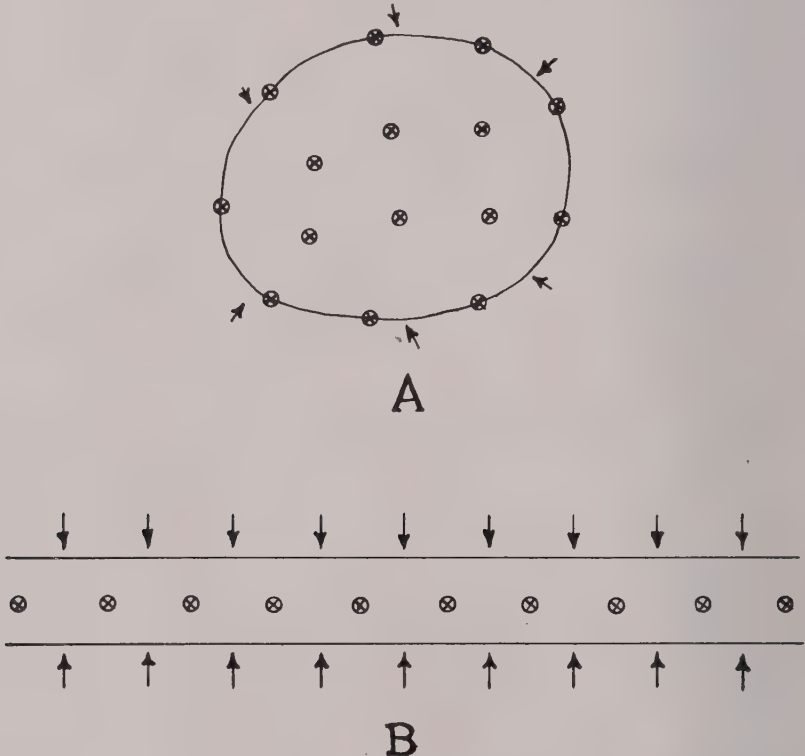

A

B

Fig. 58. (*A*) A diagramatic sketch of a field of 17-month-old cane in and around which only three stations out of fifteen showed any return activity. The reinfestation amounted to 2.8 per cent. This area is subject to reinfestation along the edges.

(*B*) A diagramatic sketch of a continuous single line (corridor) along brush land and stream, illustrating the exposure to heavy reinfestation on both sides. In this area, reinfestation amounted to 26.3 per cent in from 8 to 10 days.

The results of this test using "L-Tox" show that it was less acceptable to the field rats than had been the dried red squill-oats mixture used in Experiment 40 (14.8 per cent to 41 per cent). Both mixtures of red squill as used in these tests gave such low efficiencies as to be a complete failure as a means of practical field control. Very few rats ate sufficient "L-Tox" to obtain a lethal dose. Since most (over 85 per cent) of the poisoned bait is always consumed the first night of exposure, any spoilage of the wet "L-Tox" bait cannot be advanced as a valid cause of the poor consumption.

There is no doubt that the thallium-poisoned oats were effective as measured by the sharp reduction in consumption of unpoisoned oats following their use, but owing to the fact that most of these stations were placed in a single line in heavily infested territory and subject to reinfestation from both sides the return consumption of both unpoisoned and poisoned oats following the first thallium application was much larger than is normally the case in cane areas.

The average reinfestation over the whole test was 20.2 per cent in the short period of from eight to ten days. The contrast between the amount of reinfestation expected at stations in and around a compact field of cane, compared with the return infestation likely to occur at stations placed in a corridor across previously untreated brush land, is well illustrated in this test when segregation is made of the stations occupying each of the two situations.

Only 3 out of 15 stations in and around the circular cane field showed any activity whatever following the first thallium poisoning. The total reinfestation in this section amounted to 2.8 per cent in from eight to ten days, but the reinfestation of the narrow treated corridor across the brushland amounted to 26.3 per cent during the same length of time (see Fig. 58-A and 58-B). This illustration shows why field operations should be conducted systematically over large areas to reduce to a minimum this problem of reinfestation of the treated areas from the edges.

Cage Tests Using "L-Tox": "L-Tox" baits were prepared by moistening 5-gram portions and giving one to each caged rat. At the end of the three days all remaining bait was redried and reweighed to determine the actual net consumption. The summary of 38 trials on 27 rats is given in Table XXXI. Only seven

TABLE XXXI

SUMMARY OF CAGE TESTS USING "L-TOX"

	Rat species	No. of trials	No. of rats	Avg. body wt. grams	Unpoisoned oats eaten		
					No. of days record	Daily avg. grams	% of body weight
(1)	R. norvegicus	26	16	204.2	11.3	14.8	7.4
(2)	R. r. rattus	5	5	108.0	9.0	8.4	8.6
(3)	R. r. alexandrinus	7	6	83.1	11.4	7.1	9.2
	Totals	38	27	182.8	11.0	12.6	7.9

		Poisoned bait eaten in 3 days			
		Average grams	% of body weight	% of daily avg. unpoisoned	Deaths
(1)		2.6	1.3	17.9	5
	Average of 5 deaths	3.1	1.7	22.8	
	Average of 20 recoveries	2.4	1.26	16.7	
(2)		2.2	2.5	27.6	1
(3)		1.7	2.1	24.3	1
	Totals	2.4	1.6	20.4	7

deaths resulted from 38 trials indicating that very few rats could be persuaded to eat a lethal dose. It is interesting to note that the five Norways which died ate 1.7 per cent of their body weight of the dried "L-Tox" and that the 20 recoveries consumed only 1.26 per cent. Apparently this small difference of 0.44 per cent was a matter of life or death to these rats. The average amount eaten by all Norways (1.3 per cent) was about one third of the amount of thallium-poisoned oats that is normally accepted (4.2 per cent). This shows that the maximum amount of "L-Tox" likely to be consumed by rats is very close to the minimum lethal dose necessary.

The recoveries of all species of rats from "L-Tox" amounted to 78.9 per cent with 2.6 per cent total refusals leaving only 18.4 per cent deaths. "L-Tox" was not sufficiently attractive to the rats to induce many of them to eat a lethal dose. "L-Tox" is not a satisfactory or reliable poison for the field rat and cannot be recommended for large-scale use on the plantations in Hawaii.

Ratmort: Two field experiments (Nos. 44 and 45) were conducted at Waimanalo Sugar Company to determine the acceptance and killing power of a commercial liquid extract of red squill known as "Ratmort."*

In the first test (Experiment 44—September 1941) the consumption of unpoisoned and poisoned oats was studied in detail at 54 stations which were placed singly, spaced 60–80 feet apart in a long line around a field of mature 31–2510 cane, and a plot of panicum grass.

After a normal six-day baiting, Ratmort-poisoned oats were supplied for four days to all stations. The poisoned bait was prepared by adding the liquid Ratmort to the oats and stirring. In the first ten stations, the concentration of Ratmort was 75 cc. per pound of dry oats, and 117 cc. per pound for the remainder (44 stations).* All poisoned bait was removed after four days, and was followed immediately by a second baiting with unpoisoned oats. Thallium-poisoned oats (1–200) were then supplied to all stations to kill all survivors of the Ratmort treatment as well as any new migrants. A third baiting was followed by thallium-poisoned oats to determine the amount of migration occurring in the short period of eight to ten days. Corn oil was used uniformly as the attractant. The consumption data obtained from the use of Ratmort have been summarized in Table XXXII and illustrated in Fig. 59.

The area under treatment was so heavily infested with rats that many pans were

TABLE XXXII

SUMMARIZED DATA FROM EXPERIMENT NO. 44 EVALUATING RATMORT AS A LETHAL
AGENT IN ROLLED OATS FOLLOWED BY THALLIUM SULPHATE AS CHECK

	First period			Second period			Third period		
	Unpoisoned		Ratmort	Unpoisoned		Thallium	Unpoisoned		Thallium
Interval (days)	4	2	4	4	2	2	4	2	5
No. of active stations	54	54	54	54	54	54	25	28	38
Total oats eaten (grams).........	5135	5213	2552	5898*	4824	1725	480	498	320†
Avg. daily consumption (grams) ..	1284	2607	....	1475*	2412	....	120	249	....
Consumption—% of highest 2 days	49	100	98	57	93	66	4.6	9.6	12.3

*Maximum available—pans were empty.
†Mice and cockroaches carried away some of the poisoned grain during the five days of exposure of thallium-treated oats.

*Ratmort is manufactured by the West Disinfecting Company, of Long Island City, New York. Active ingredient—solid extract of red squill 10 per cent. Inert ingredient—90 per cent.
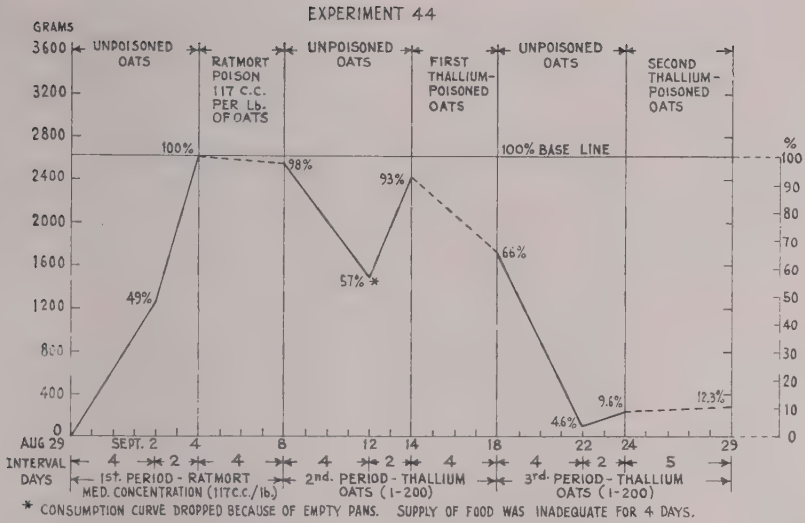
Fig. 59. The average daily total amount of unpoisoned and Ratmort-poisoned oats eaten by rats, in grams, at fifty-four stations during a feeding period, followed by two successive periods of unpoisoned and thallium-poisoned oats.

The base line (100%) represents the average of the two best days of consumption before the first attempt was made to poison the rats (from Table XXXII).

empty on the first reading of unpoisoned oats, but on the second reading only one pan was empty, so the top consumption figure was not appreciably affected. The rats ate the Ratmort-oats mixture so well that in four days of exposure they ate all of the mixture in many pans. The total amount of Ratmort oats eaten was almost the same as the highest consumption of unpoisoned oats in one night. During the subsequent baiting enough of the original population together with the transients returned to total a clientele of 93 per cent. This showed that the kill was only seven per cent of the original population plus the amount of infestation by transients.

From Table XXXII and Fig. 59 we note the number of rats returning to eat during the third exposure of unpoisoned oats (following thallium poisoning) to be a maximum of 9.6 per cent as much as the original population. Therefore the maximum kill for the Ratmort treatment could not exceed 7 plus 9.6 or 16.6 per cent.

These results indicate that Ratmort at the concentration of 117 cc. per pound is readily accepted but ineffective as a poison for rats. Only about one-sixth of the field population was killed by this treatment.

The second test (Experiment 45) sought to determine at what higher concentration Ratmort would be accepted in sufficient quantity to be lethal. To this end 34 stations were studied from August 20 to October 16, 1941. The measurements and records were handled as previously described, but the strength of the Ratmort was successively increased from 57 cc. (low) to 125 cc. (medium) to 230 cc. (high) per pound of oats through three successive periods. The three exposures of Rat-

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*The directions given by the West Disinfecting Company say to mix Ratmort with baits like oatmeal, corn meal, fish, or unseasoned ground cooked meat until mixture is of the consistency of thick paste. This does not give an exact amount by measure.

mort were followed by two periods of baitings and poisonings with thallium-treated oats. The first of these thallium treatments was made for the purpose of evaluating the proportion of the original population which had survived the Ratmort applications, and the second thallium treatment was made to determine the amount of reinfestation that could be expected during a single period of treatment. The concentration of thallium sulphate in the oats bait was 1–200. Corn oil was used uniformly as the attractant.

The detailed consumption data were tabulated and summarized in Table XXXIII and illustrated in Fig. 60.

TABLE XXXIII

SUMMARIZED DATA FROM EXPERIMENT NO. 45 EVALUATING RATMORT AS A LETHAL AGENT IN ROLLED OATS FOLLOWED BY THALLIUM SULPHATE AS CHECK

		First period				Ratmort 57 cc./lb.	Second period					Ratmort 125 cc./lb.	
		Unpoisoned					Unpoisoned						
(1)	Interval (days) ..	2	3	2	2	4	1	1	2	2	2	2	2
(2)	No. of active stas.	32	34	33	34	34	34	34	34	34	33	34	34
(3)	Total oats eaten (grams)	2136	3399	1982	2119	1185*	899*	1903	2693	2727	2108	788.8	506.2
(4)	Avg. daily consumption (grams).	1068	1133	991	1060	....	899*	1903	1347	1364	1054	1295	....
(5)	Consumption—% of 9-day average..	....	....	....	100	110.6	83.9	177.7	125.8	127.4	98.4	120.8	

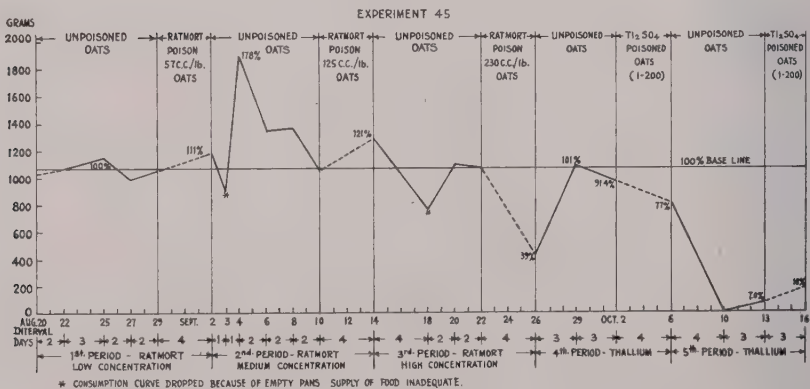|	Third period					Fourth period		Thallium 1/200	Fifth period		Thallium 1/200
	Unpoisoned			Ratmort —230 cc./lb.		Unpoisoned			Unpoisoned		
(1)	4	2	2	2	2	3	3	4	4	3	3
(2)	34	34	34	33	28	34	34	34	3	14	15
(3)	3147*	2208	2152	272.2	149.7 422	3244	2937	822	34	229	198
(4)	788*	1104	1076	...		1081	979	....	8.5	'76	....
(5)	73.6	103.1	100.5	39.4		100.9	91.4	76.8	0.8	7.1	18.5

*Maximum available—pans were empty.

Fig. 60. The average daily total amount of unpoisoned and Ratmort-poisoned oats eaten by rats at thirty-four stations during three successive periods of feeding, followed by two successive periods of feeding of unpoisoned and thallium-poisoned oats (from Table XXXIII).

The feeding stations in this test had already established a good clientele during a previous study of colored baits, so the average consumption for the first nine days (from Table XXXIII) was taken as the base line of 100 per cent used in Fig. 60.

The first application of low concentration (57 cc. per pound) of Ratmort was readily accepted by the rats but resulted in no appreciable kill. The daily readings of unpoisoned bait immediately following indicated a large number of hungry rats who ate all available food the first day, emptying the pans. During the second day they ate more than a normal day's food to break their "fast"; then as food continued plentiful in the pans, daily consumption returned to near normal.

The second application of Ratmort-poisoned oats (125 cc. per pound) was again readily accepted but resulted in a relatively low kill (estimated at 15 per cent). Following these four days of low consumption of Ratmort, there was a heavy consumption of unpoisoned oats with resulting empty pans (Sept. 18—see Fig. 60).

The highest concentration of Ratmort (230 cc. per pound—Sept. 22-26) was not so acceptable to the rats as the former concentrations. The consumption dropped to 39 per cent showing a distinct aversion for this higher red squill content. These stations were visited at two-day intervals. Additional consumption occurred even during the third and fourth nights (see Table XXXIII—the two readings under heading of "Ratmort-Poisoned Oats" in the third period showed some consumption) demonstrating that the rats returned each night and sampled the Ratmort, but the quantity consumed during any one night was very small. The rats returned each night apparently looking for a more palatable food. The amount eaten was dependent on their reaction to the taste at the time.

This highest concentration of Ratmort gave even less kill (estimated at 10-12 per cent) than the former trials as practically the same population returned during the following baiting period.

After this last application of Ratmort, unpoisoned oats were again supplied followed by thallium-treated oats which were accepted in about the usual amount and proved very effective—so effective in fact that during the fifth period of baiting, transients attracted to the unpoisoned bait amounted to a maximum of seven per cent only. During the final application of thallium-poisoned oats, however, new migrants brought the acceptance higher (18 per cent) than the unpoisoned acceptance, which is very unusual.

The net kill by Ratmort appeared to be little more than the amount of the transients and certainly did not exceed 10-12 per cent. Since the increased concentration of Ratmort caused the development of such a high percentage of refusals without effective kills, there was no hope of varying the concentrations to attain success with Ratmort.

That the previous low concentrations of Ratmort in this test made these rats bait shy when higher concentrations were exposed is a valid argument. If this be true the use of high concentrations on the first exposure should have been more effective. Granting this point, it is still too much to expect the possible improvement to be of sufficient magnitude for satisfactory control of field rats on sugar plantations.

Cage Tests with Ratmort and Rodite* Biscuit: Only 11 trials on six rats, aver-

*Rodite is a specially prepared cracker containing red squill to form a raticide in the form of a prepared bait completely ready for use. This product is manufactured by the West Disinfecting Company of Long Island City, N. Y.

aging 91.5 grams in weight, were made using these commercial forms of red squill. The consumption rate of this poisoned mixture was about the same as for thallium-poisoned bait. This amounted to 65.8 per cent of the average daily consumption of unpoisoned oats. However, out of nine trials with Rodite cake there were only two deaths. No deaths resulted from two trials with Ratmort. Due to the generally poor showing of these products they were discarded without further testing.

After conducting these tests, the writer feels that until such time when a more highly toxic and stable extract of red squill is available, the possibilities of its success are not sufficiently bright to warrant any further study.

Yellow Phosphorus: Yellow phosphorus has been used extensively as a rat poison. It has a distinct odor and taste as well as characteristic fuming and luminous properties which definitely identify it. This poison is extensively used in commercial rat paste but it is not suited for dry baits as it deteriorates rapidly when exposed to drying. The actively poisonous yellow phosphorus oxidizes to red phosphorus which is relatively non-poisonous.

Pemberton (62, p. 27) reported on six tests using phosphorus mixed into flour dough and dried. While the rats ate this bait and died within two days, yet, " . . . field experiment with this material indicated a too rapid deterioration."

Phosphorus paste is an effective rat poison when applied in a fruit or bread bait as long as it is fresh. According to Fox (30, pp. 37–39), the field distribution during dry weather of phosphorus paste on bread cubes has given good results in Queensland. The possibility, though remote, that phosphorus paste might become a fire hazard when dry, has definitely limited its use in our cane fields.

Bananas make one of the best phosphorus carriers. Montserin (54, pp. 8–11) has reported a novel and successful plan of poisoning the tree rat which attacks the cacao in Trinidad by the use of banana poisoned with phosphorus in the form of matches, which are known locally as "sulphur matches." Instructions for baiting with bananas and matches are given by Montserin as follows:

A ribbon of the peel about one inch wide is removed from one surface; if the fruit is curved, it would be more convenient to remove the peel from the concave surface. The match heads are forced through the adhering peel on the sides into the center of the pulp; the other ends are allowed to project like the oars of a boat. The number of matches required varies according to the size of fruit from 10 to 14. Half of the required number is inserted on each side of the fruit. Large bananas are cut into three portions, each of which constitutes a bait. The baits are placed in the forks of branches or other places frequented by the rats. They should be placed out of the reach of poultry and domestic animals.

Banana baits are effective over a period of 48 hours after which the pulp begins to break down and the bait loses its attractiveness. In the case of the Tree Rat, however, the baits are almost invariably taken during the first night.

The Board of Health, Territory of Hawaii, reports good acceptance of fresh phosphorus banana baits by *Alexandrinus* rats. Dr. Trotter (85, p. 209) related in the annual report of the Board of Health of Hawaii for 1939 that Major A. L. Dopmeyer of the U. S. Public Health Service had made extensive use of banana phosphorus baits in his plague control work on the islands of Maui and Hawaii. He reported that indications of the effectiveness of this phosphorus bait were evident by the tremendous increase in the number of dead rats that he found during the fiscal year of 1939 after the treatment was inaugurated compared with the previous years. The phosphorus banana bait consisted of pieces of banana loaded with a

paste containing yellow phosphorus as the lethal agent. This bait was prepared by cutting half-ripe bananas into 1½ to 2-inch segments, partially splitting these pieces lengthwise, then removing a small rounded piece of pulp from the center by means of a small fruit pitter, and filling the cavity with "Rat-Nip"* or "Seneco"† phosphorus paste. The two halves of the banana bait were closed together and pinned by means of tooth picks. These baits, when made with half-ripe bananas, lasted about six days under field conditions before they deteriorated.

Field Experiments Using Yellow Phosphorus Paste: Two field tests (Experiments 42 and 43) were carried out to determine the acceptance and effectiveness of Rat-Nip containing yellow phosphorus, using the prebaited feeding-station system.

In the first test conducted at Kailua Substation (Experiment 42—Oct. 1940) the 49 feeding stations were spaced singly 70–90 feet apart in a long line bordering brush land and a stream where rats were abundant. Corn oil was used as the attractant in all baits. This experiment was conducted through three periods of treatment. The first treatment covered a period of six days of baiting with unpoisoned rolled oats followed by four days exposure of a bait containing a concentration of 30 per cent by weight, of Rat-Nip paste in rolled oats.‡ In order to determine the number of survivors and migrants, the second treatment began with six days baiting with unpoisoned oats as before but was followed by thallium-poisoned oats (1–200) for four days. The third treatment was a repeat of the second treatment for the purpose of determining the amount of reinfestation that occurred during the period of treatment (ten days) in the area under study.

The consumption of oats was measured and recorded for each period. The detailed consumption data were tabulated and summarized in Table XXXIV and are illustrated in Fig. 61.

The entire area along the stream and wasteland covered by this test harbored more rats than was estimated consequently there was a large number of empty pans when the readings were made. Thus, the maximum peak of consumption (100 per cent base) was not set as high as it might have been. The acceptance of Rat-Nip-treated oats (counting the extra weight of Rat-Nip per unit of volume) was better than normal acceptance of thallium-poisoned oats (94.6 per cent of the average of the two best nights of baiting).

The return consumption of unpoisoned oats following the Rat-Nip-treated oats amounted to almost (97.5 per cent) as much as had been consumed formerly before the Rat-Nip treatment. This indicated that a low mortality had resulted from this excellent acceptance. The final figures following the second thallium poisoning in-

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*"Rat-Nip" is a commercial preparation containing 1.8 per cent yellow phosphorus as the active ingredient. This product is manufactured by the Liquid Veneer Company, of Buffalo, New York.

†"Seneco" or Sennewald Phosphorus Paste is distributed by Sennewald Drug Company, Inc., 300 Hickory St., St. Louis, Missouri.

‡To prepare the poisoned mixture, commercial Rat-Nip paste was added at the rate of 135 grams to one pound of oats (30 per cent by weight). This mass was thoroughly stirred with a wooden paddle. The mixture fumed heavily for some time. After 24 hours the material had dried enough to handle reasonably well without sticking together.

The 30 per cent Rat-Nip-and-oats mixture settled together and was so heavy that one measuring cup of the mixture weighed approximately 173 grams compared with 113.4 grams for dry rolled oats. This weight difference has been adjusted in Table XXXIV.

dicated a heavy reinfestation of rats approximately 18–19 per cent into this treated "corridor" in ten days. Dead rats were found in the treated area following the Rat-Nip treatment but the mortality must have been less than 25 per cent. Under similar conditions of reinfestation, thallium sulphate would have produced a mortality of 80 per cent (refer to third poisoning).

Since the acceptance of 30 per cent Rat-Nip-treated oats was satisfactory but the kill was inefficient when compared with thallium it was necessary to increase the concentrations of the poison in the bait while hoping to maintain a reasonably satisfactory acceptance. This was done in the following test (Experiment 43, Sept. 1941, Waimanalo Sugar Company) when a 50 per cent Rat-Nip-rolled-oats mix-
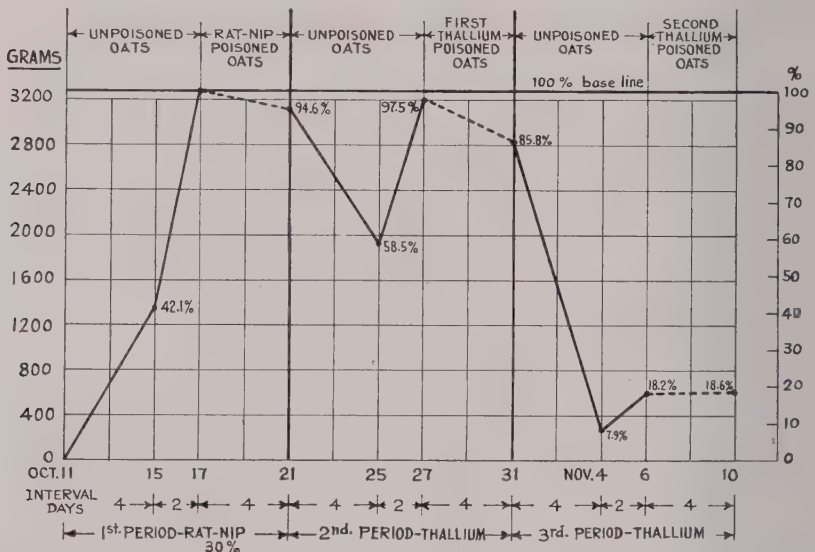
PROJECT A-108 EXPERIMENT 42

Fig. 61. The average daily total amount of unpoisoned and Rat-Nip-poisoned oats (30 per cent) eaten by rats at forty-nine stations and followed by two successive periods of unpoisoned and thallium-poisoned oats (from Table XXXIV).

TABLE XXXIV

SUMMARIZED DATA FROM EXPERIMENT 42 EVALUATING THE KILLING POWER OF 3 PER CENT RAT-NIP IN ROLLED OATS FOLLOWED BY THALLIUM SULPHATE AS CHECK

| | First period | | | Second period | | | Third period | | |
	Unpoisoned	Rat-Nip	Unpoisoned		Thallium	Unpoisoned		Thalliu
Interval (days)	4	2	4	4	2	4	4	2	4
No. of active stations	49	49	49	49	49	49	30	37†	41
Total oats eaten (grams).........	5542*	6585*	3114‡	7704.4	6417.3	2824.8	1039.9	1198.6	613.5
Avg. daily consumption (grams) ..	1385.5	3292.6	....	1926.1	3208.7	....	260	599.3	....
Consumption—% of highest 2 days	42.1	100	94.6	58.5	97.5	85.8	7.9	18.2	18.6
Consumption—% of highest 2 days	....	....	....	....	100	88.0	8.1	18.7	19.1
Ratio: poisoned to unpoisoned oats		1:5.9			1:4.6			1:3.6	

*Maximum amount available—empty pans.
†Mice account for much of the increased activity.
‡Weights adjusted to compensate for the increased weight per unit of volume of 30 per cent Nat-Nip bait compared with dry rolled oats.

ture* was studied. The 52 stations were placed singly, spaced 60–80 feet apart, around panicum grass waste area, a reservoir, and adjacent cane. Corn oil was used uniformly throughout the test as the attractant. The treatments in this test were identical with those previously described for Experiment 42.

The detailed consumption data were tabulated and summarized in Table XXXV and illustrated in Fig. 62. For convenience in comparing the results of Experiment 42 (30 per cent Rat-Nip), Experiment 43 (50 per cent Rat-Nip), and Experiment 44 (Ratmort—red squill extract) the data of all three tests have been converted to per cent and plotted on Fig. 63.

TABLE XXXV

SUMMARIZED DATA FROM EXPERIMENT 43 EVALUATING THE KILLING POWER OF 50 PER CENT RAT-NIP IN ROLLED OATS FOLLOWED BY THALLIUM SULPHATE AS CHECK

	First period			Second period			Third period		
	Unpoisoned		Rat-Nip	Unpoisoned		Thallium	Unpoisoned		Thallium
Interval (days)	4	2	4	4	2	4	4	2	5
No. of active stations	52	52	52	48	50	52	23	31	32†
Total oats eaten (grams)........	5462	6997	1617‡	2945	2487	1097	630	668	261†
Avg. daily consumption (grams) ..	1366*	3499	....	736	1244	....	158	334	....
Consumption—% of highest 2 days	39	100	46	21	36	31	4.5	9.5	7.5

*Maximum amount available—empty pans.

†Mice and cockroaches account for much of the missing grain during the 5-day exposure of poisoned oats in the third period.

‡Weights adjusted to compensate for the increased weight per unit of volume of 50 per cent Rat-Nip-treated oats compared with dry rolled oats.
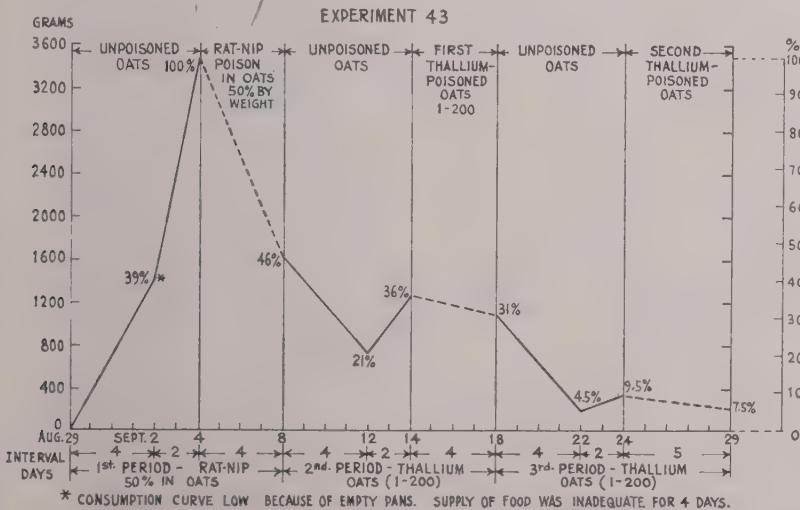

Fig. 62. The average daily total amount of unpoisoned and Rat-Nip-poisoned oats eaten by rats at fifty-two stations and followed by two successive periods of unpoisoned and thallium-poisoned oats (from Table XXXV).

*The 50–50 Rat-Nip and oats mixture is much heavier per unit of volume than dry oats. One measuring cup of this mixture weighs approximately 220 grams compared with 113.4 grams for rolled oats. This weight difference was adjusted in Table XXXV.

The areas chosen for this test harbored more rats than was anticipated, consequently there was a large number of empty pans when the first readings were made. Only a few pans were empty on the second and final unpoisoned reading so this condition did not appreciably affect the peak consumption figures.

The acceptance of the 50 per cent Rat-Nip mixture during four days of exposure was 46 per cent of the amount of unpoisoned oats eaten in a single night just previous to the poisoning. This amount was only half as much as had been accepted of the 30 per cent Rat-Nip mixture used in Experiment 42, showing that the increased concentration had reduced consumption to one half. But the subsequent exposure of the unpoisoned oats showed a return clientele of only 36 per cent (compared with 92.5 per cent for the 30 per cent mixture) indicating a heavy kill produced even by this smaller consumption.

The survivors (36 per cent) accepted thallium-treated oats during the following poisoning without any suspicion as evidenced by the favorable per cent of acceptance (31 vs. 36).

The third baiting and poisoning period showed that the reinfestation by transient rats over a period of ten days amounted to approximately 5–9 per cent of the original population.
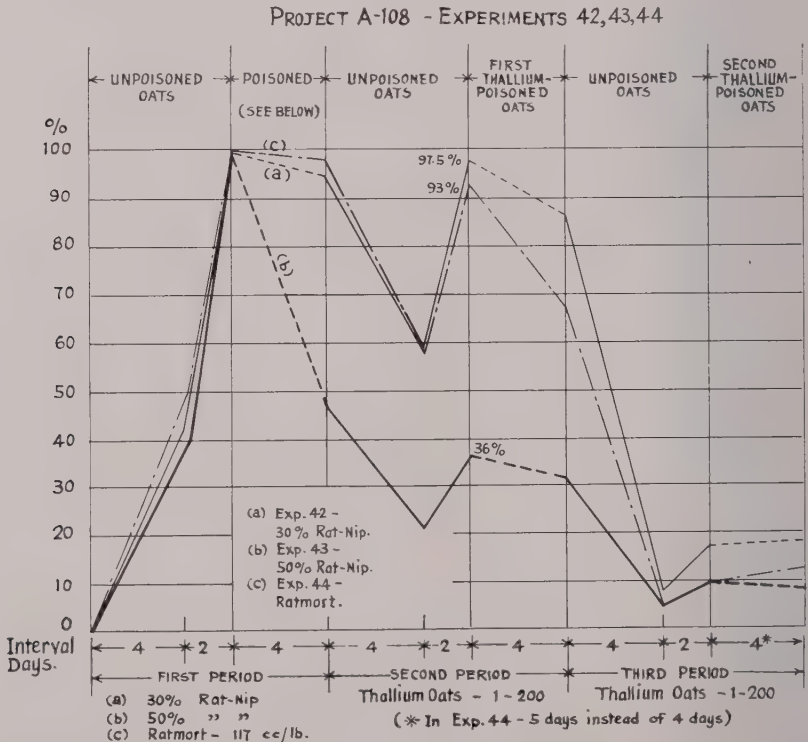

PROJECT A-108 - EXPERIMENTS 42,43,44

Fig. 63. The average daily consumption of unpoisoned and poisoned bait by rats in per cent for three experiments, comparing 30 per cent Rat-Nip, 50 per cent Rat-Nip and Ratmort respectively, during the first period, followed by two periods of unpoisoned and thallium-poisoned oats. The average of the two best days' consumption of bait before any poison was given was taken as 100 per cent base (from Tables XXXII, XXXIV, and XXXV).

This condition operated to add to the total population of rats available for poisoning during the second period when thallium was used as the lethal agent. Thus the 36 per cent of active clientele surviving the Rat-Nip treatment includes these transients. Had there been no transients the kill of a static population would have been 100 minus 36 per cent or 64 per cent, but correcting for the transients we have 64 plus 5 to 9 or *69 to 73 per cent* actual kill based on the original population.

These results show that while the 50 per cent Rat-Nip-oats mixture is only half as acceptable as the 30 per cent mixture, the killing power is approximately 70 per cent compared with approximately 25 per cent for the weaker mixture.

Cage tests indicate that 39–40 per cent concentration is the critical point above which the Rat-Nip mixture is very deadly.

Cage Studies: Phosphorus bait for cage studies was prepared by adding phosphorus paste (containing 1.8 per cent yellow phosphorus) to dry rolled oats in two concentrations (30 per cent and 39–40 per cent by weight) and mixing thoroughly. This mixture was used very soon after preparing before much drying could occur which would materially reduce its potency.

These cage tests were conducted in the same manner as previously described. The results of this series of trials have been summarized and are given in Table XXXVI.

TABLE XXXVI

SUMMARY OF CAGE TESTS USING PHOSPHORUS PASTE IN ROLLED OATS AT CONCENTRATIONS OF 30 PER CENT, AND 39–40 PER CENT

				Unpoisoned oats eaten			Poisoned-oats eaten in 3 days		
Rat species	No. of trials	No. of rats	Avg. body wt. gms.	No. of days record	Daily avg. gms.	% of body wt.	Avg. gms.	% of body wt.	% of daily avg. un-poisoned
R. norvegicus	21	14	219.1	8.8	15.6	7.5∓.4	7.5	4.1∓.7	52.8
R. r. rattus	19	16	113.2	10.5	9.0	8.2∓.7	4.9	4.3∓.6	57.6
R. r. alexandrinus	28	21	92.4	14.3	7.9	8.6∓.4	3.4	4.2∓.9	48.9
Totals	68	51	140.1	11.5	10.6	8.1∓.3	5.1	4.2∓.2	52.7

Remarks:

R. norvegicus—7 deaths, 1 refusal; 13 recoveries (12 in 30% group).

R. r. rattus—13 deaths (2 deaths from 30% mix); 3 recoveries.

R. r. alexandrinus—19 deaths (4 deaths from 30% mix); 2 refusals (same rat); 7 recoveries.

Segregation by Concentration of Poison in Oats

	Phosphorus paste 30%			Phosphorus paste 39–40%	
	No. rats	% of total		No. rats	% of total
Deaths	6	31.6	Deaths	36	73.5
Recoveries	12	63.2	Recoveries	11	22.4
Refusals	1	5.2	Refusals	2	4.1
	19	100.0%		49	100.0%

A 30 per cent mixture was used in the first 13 trials on a group of *R. norvegicus* which resulted in no deaths, but this same concentration used in two trials on *R. r. rattus* and four trials on *R. r. alexandrinus* resulted in six deaths.

The concentration of phosphorus paste in oats was then increased to 39–40 per cent and used in 8 trials with *R. norvegicus* resulting in 7 deaths and one survivor. This outcome gave a definite indication that the 30 per cent concentration was too low for Norways in the first instance.

Attention is called to the fact that the use of increased concentrations of this

poison was accompanied by reduced acceptance. The rats ate 5.3 per cent of their body weight of the 30 per cent mixture but only 3.7 per cent of their body weight of the 39–40 per cent mixture.

There were three cases of recoveries following the consumption of the 39–40 per cent phosphorus paste mixture which need an explanation. It is believed that the material had become so completely dried out that it was no longer toxic.

The average acceptance by rats of poisoned bait containing phosphorus paste amounted to $4.2 \mp .2$ per cent of their body weight. It is of interest that this is identical with the amount of thallium-treated oats eaten by rats in other trials. Death occurred any time from 6 to 8 hours to as much as 100 hours after the poison had been placed in the cages. Many deaths occurred in from 10 to 20 hours.

Phosphorus paste, when used fresh in a concentration of more than 38 per cent with rolled oats, killed 73.5 per cent of the rats with 22.4 per cent recoveries and 4.1 per cent refusals. This is considered very good and gives phosphorus paste third place in rank of effective poisons tried out on rolled oats, being surpassed only by thallium sulphate and zinc phosphide.

Zinc Phosphide: Zinc phosphide has recently come into prominence as a substitute for thallium sulphate in Hawaii because of the scarcity of the latter during World War II. None of the other standard rat poisons (excepting thallium) has approached zinc phosphide in efficiency when used in a dry cereal bait for large-scale operations. It has such promise of continued usefulness in dry baits that the writer ventures the opinion that zinc phosphide will entirely replace thallium sulphate in regions where secondary poisoning (from thallium sulphate which will be discussed later) kills the natural enemies of the rat. The importance of this chemical in future rat-control work warrants giving at this time more details concerning its properties.

Zinc phosphide (53, p. 589) (Zn_3P_2) is a "Dark gray, lustrous or dull powder" with a "faint phosphorus odor," having a molecular weight of 258.18 made up of 75.9 per cent zinc and 24.03 per cent phosphorus. Zinc phosphide slowly evolves elemental phosphorus by volatilization in dry storage, which accounts for the faint odor of phosphorus. Commercial zinc phosphide is said to be "80–85 per cent pure . . . the balance consisting of some metallic zinc, phosphide and phosphate." This chemical is "insoluble in water, [or] alcohol," but soluble in hydrochloric acid (HCl), sulphuric acid (H_2SO_4) with the evolution of spontaneously inflammable and very poisonous phosphine gas. It will react violently with concentrated sulphuric acid (H_2SO_4), hydrogen (H), nitrate (NO_3) and other oxidizing agents. As zinc phosphide powder decomposes slowly in moist air liberating phosphine gas, it is very necessary that it be kept absolutely dry while in storage. Phosphine is a colorless gas with a disagreeable garlic-like odor.

A review of the literature covering its agricultural uses shows that in France as early as 1931, Aurivel (3) reported on the control of the mole by the use of sublimated zinc phosphide dusted on water-soaked cracked rice. Kassab (42) in 1936 reported on the preparation and method of application of zinc phosphide bait employed successfully in the control of mole crickets, *Gryllotalpa,* in Egypt. Here the bait was composed of crushed maize or rice 100 parts, water 25, and zinc phosphide 5 parts.

Dr. Hans Klauer (43) reporting to the 23rd meeting of the Deutsche Zeit. fur

die gesamte gerichliche medizin, in 1934 at Hannover, Germany, first pointed out the danger of the phosphorus-containing mouse poison "Delicia." According to his conclusions, this preparation gave off phosphine gas on warming or boiling. Elbel (25) stated that this mouse poison was composed of cereal grains which were coated with a poison layer containing three per cent zinc phosphide and a red dye. The poisoned bait gave off a red dust when stirred or poured. A chemical test of this dust revealed seven per cent of zinc phosphide. Therefore a considerable poisoning action should result and this was confirmed by experiments with guinea pigs.

An accidental poisoning of an agricultural worker from this dust was reported by Elbel (25) in 1935. This is the only specific instance of a field worker being poisoned from handling this chemical that is reported in the available literature. However, some of the symptoms are given in the following translation by Dr. H. P. Kortschak of this Experiment Station:

A few hours after the worker finished for the day, he became ill with vomiting and diarrhea. The symptoms were so threatening that he had to be taken hurriedly to the medical clinic in Göttingen.

The following symptoms were found. Cyanosis, rattling in the throat, faint, intermittent pulse of 100 frequency, a bloated, pressure-sensitive abdomen, great restlessness, protein in the urine, temperatures 38.4° C (101° F. tr.). An X-ray showed a slight exudate of the right sinus and the lung capillaries too full of blood. A satisfactory diagnosis could not be made.

The condition improved in several days following symptomatic therapy and after two weeks the patient recovered and was dismissed.

Klauer (43) in 1935 described symptoms in cases of phosphine poisoning in humans somewhat as follows (translation by Kortschak):

A feeling of chills lasting several days, difficulty in breathing, with a tight feeling in the chest, and piercing pains back of the collar bone which may increase to cases of suffocation, coughing, interrupted pulse, great weakness, with fainting spells, dizziness, roaring in the ears, and digestive disturbances. Such cases of poisoning have often been taken to be ptomaine poisoning, typhus or cerebrospinal meningitis. The duration of suffering until death may be from one to three days.

[According to Klauer (43)] Lowin found that the autopsy showed nothing characteristic; also that Kobert claimed that in sub-acute and chronic cases there was sometimes slight fatty degeneration of the liver.

[Klauer (43) also gave further symptoms (discussion by Flury and Zernik):] Hyperaemia of the trachea and lungs, with bleeding, further adiposis of the organs, and in acute cases, edema of the lungs. Very small, strongly refractive grains were often found in the blood. Klauer further stated that Meissner could find no symptoms on himself while staying in an atmosphere smelling strongly of phosphine gas, but Huhnefeld had pains in the region of the diaphragm, with a feeling of cold and chills.

The point of attack of phosphine was said to be, obviously, the central nervous system, which became paralyzed after short irritation. Parallel to this there was assumed to be an effect on the blood vessels.

Klauer gave a table (by Flury and Zernik*) on the strength of phosphide gas as a poison for man as follows:

	mg/l	c/cbm
Rapidly fatal	2.8 or	2000
Fatal in 1½ hours or later	0.56–0.89 or	400–600
Very dangerous in 1½ hours	0.4–0.6 or	290–430
½ to 1 hour without immediate or subsequent consequences	0.14–0.26 or	100–190
Effective after several hours (still some fatal cases after 6 hours)	0.01	7
Limit of effectiveness	0.002–0.004 or	1.4–2.3

*"Harmful gases" by Flury and Zernik, 1931, Berlin.

That cases of phosphine poisoning are rather rare, and almost exclusively factory accidents, are probably due, primarily, to the unpleasant odor by which even traces of phosphine can be detected.

Henderson and Haggard (39, p. 243) made the following comments on the poisonous effects of phosphine:

The toxicology of acute poisoning by phosphene has not been fully worked out. It does not alter the blood and its effects are apparently exerted largely through the central nervous system. Some inflammation of the lungs results from its inhalation; beyond this, no changes in the body are demonstrable.

The acute action of phosphene does not resemble that of phosphorus. Instead, there is marked dyspnea, purgation, weakness, tremor, and finally, violent convulsions and death. The symptoms in many ways resemble those resulting from food poisoning and have been mistaken for them. Mild cases recover without after-effects.

Prolonged exposure to small amounts of phosphene is said to give rise to chronic symptoms similar to those of phosphorus poisoning.

Table 43. Physiological Response to Various Concentrations of Phosphene.

	Parts of phosphene per million parts of air
Maximum concentration allowable for prolonged exposure................	2
Slight symptoms after exposure of several hours.........................	7
Maximum concentration that can be inhaled for 1 hour without serious consequences	100 to 200
Dangerous after exposure of 30 minutes to 1 hour.......................	400 to 600
Fatal after exposure of 30 minutes....................................	1,000 to 2,000

Jacobs (41, p. 622) gives approximately the same concentration of phosphine gas, as above, in his Table 3 showing acute physiological response to gases and vapors in air.

According to the National Safety Council Inc. (58, p. 6) the maximum allowable concentration of phosphine gas is two parts per million. This limit has been adopted by the Wisconsin Industrial Commission, the Massachusetts Department, and the California Industrial Accident Commission.

Antidote for Zinc Phosphide: In case of accidental poisoning by zinc phosphide, Garlough (37, pp. 18–19) recommends that the following treatment should be given:

1. Give an emetic of mustard.

2. After vomiting has ceased, completely dissolve one tablet (5 grs.) of potassium permanganate in a glass of warm water and take.

3. After 10 minutes, give ½ teaspoonful of copper sulphate in a glass of water.

4. Fifteen minutes later, give 1 tablespoonful of epsom salts in a glass of water.

Give demulcent drinks, avoid all oils. Call a doctor.

We suggest that this information be made a part of the label on any supply of zinc phosphide kept by plantations.

Field Tests with Zinc Phosphide: *A study was inaugurated to test the efficiency of zinc phosphide when compared with thallium sulphate in separate areas without an alternate choice.*

The first field experiments with zinc phosphide in Hawaii were carried out in late May 1942 at Kaeleku Sugar Company at Hana, Maui. The object was to determine the acceptance and effectiveness of zinc phosphide when applied to rolled oats

in a standard prebaiting field test (Experiment 47—May 1942) and to compare these results with those obtained from the use of thallium sulphate under the same conditions (Experiment 48—June 1942).

The zinc-poisoned oats were prepared by first adding the required (1–200) dry zinc phosphide powder to coconut oil* (one quart to 20 pounds of oats), stirring the powder into suspension in the oil, then sprinkling the oil-zinc mixture on the rolled oats. Promptly after the addition of the oil-poison mixture, the oats were thoroughly stirred. The thallium-poisoned oats had been commercially prepared by the Pacific Chemical and Fertilizer Company at a concentration of 1–200 with coconut oil used as the attractant.

The preliminary baiting period of six days for both experiments had been carried out simultaneously by the plantation rat-control gang. Therefore, only one record of the total consumption of oats for the baiting period was obtained. It was noted that there was a larger rat population in the area chosen for the zinc treatment than in the area chosen for the thallium treatment. This was made definite by the fact that there were many more empty pans in the zinc-test area than in the thallium area. The amounts of oats consumed in both tests during the poisoning period were measured and recorded for the first and second night separately and then the last record was made following the fourth night.

Unpoisoned oats were again returned to all pans of both experiments for six days to determine the number of migrants, and the number of rats that failed to find the stations during the first period. This was followed by a second poisoning using thallium in both tests.

The detailed consumption data for the tests were tabulated, and summarized in Tables XXXVII and XXXVIII and illustrated in Figs. 64 and 65.
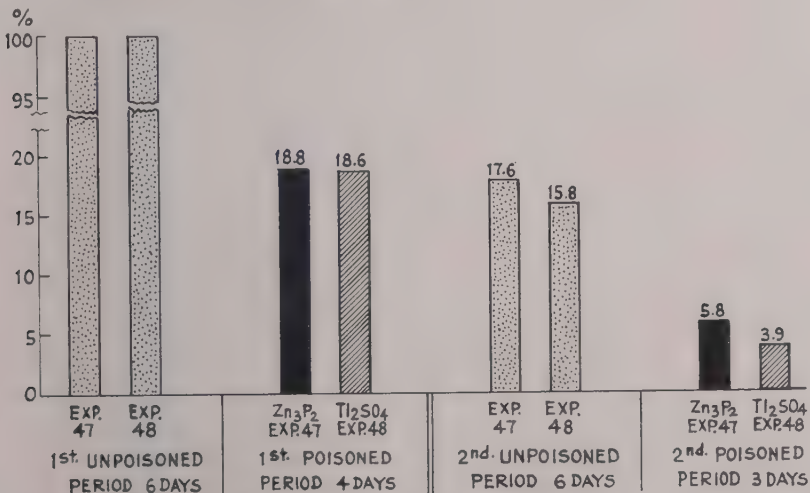

Fig. 64. Graphic presentation showing the consumption of unpoisoned and poisoned oats in per cent of the first unpoisoned period for two experiments which tested zinc phosphide and thallium sulphate respectively (from Tables XXXVII and XXXVIII).

*This was a commercial refined product obtained from McKesson & Robbins Inc. It was clear and free from sediment, and had much less of the fresh aroma which is characteristic of our local crude product.

TABLE XXXVII

SUMMARIZED DATA FROM EXPERIMENT 47 EVALUATING THE KILLING POWER OF ZINC PHOSPHIDE IN ROLLED OATS

| | First period | | | | Second period | |
	Unpoisoned			Poisoned	Unpoisoned	Poisoned
Interval (days)	6	1	1	2	4	2	3
No. of active stations	62	62	48	37	56	59	59
Oats eaten (grams)	22,406*	3472	484	252	1926	2009	1292
Total oats eaten (grams)	....	....	....	4208	....	3935	....
Distribution of poison acceptance by days in % 1st poisoning only	....	82.5	11.5	6	....	....	....
Consumption—% of first baiting ..	100	....	....	18.8	....	17.6	5.8
Consumption—% of second baiting	....	....	....	....	....	100	32.8
Ratio: poisoned to unpoisoned oats	1:5.3				1:3		

*Empty pans.

TABLE XXXVIII

SUMMARIZED DATA FROM EXPERIMENT 48 EVALUATING THE KILLING POWER OF THALLIUM SULPHATE IN ROLLED OATS

| | First period | | | | Second period | |
	Unpoisoned			Poisoned	Unpoisoned	Poisoned
Interval (days)	6	1	1	2	4	2	3
No. of active stations	58	58	38	10	34	38	43
Oats eaten (grams)	14,918	2384	326	71	957	1400	581
Total oats eaten (grams)	....	....	....	2781	....	2357	....
Distribution of poison acceptance by days in % 1st poisoning only	....	85.7	11.7	2.6	....	....	....
Consumption—% of first baiting ..	100	....	....	18.64	....	15.8	3.9
Consumption—% of second baiting	....	....	....	....	....	100	24.6
Ratio: poisoned to unpoisoned oats	1:5.4				1:4.1		

PROJECT A-108 – EXP 48

Relative Amounts of Zinc Phosphide and Thallium Sulphate Eaten Each Night of The Poison Period
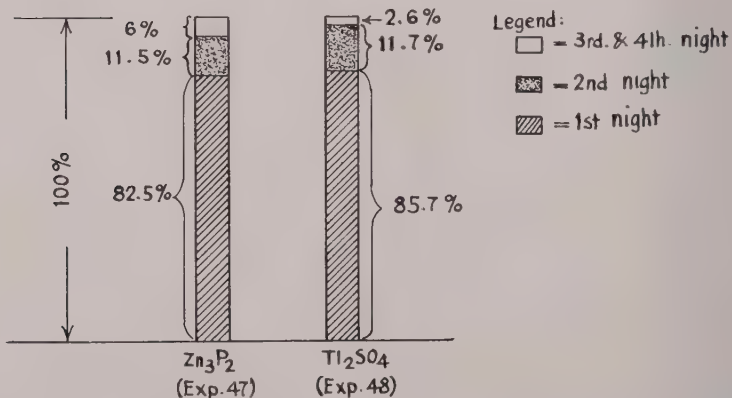
Fig. 65. Graphic presentation of the proportionate amounts of poisoned bait consumed by rats during consecutive nights, expressed in per cent, comparing zinc phosphide with thallium sulphate (from Tables XXXVII and XXXVIII).

These experiments were located in an area supporting a very high rat population. This was especially true of Experiment 47 (zinc phosphide) located for the most part in a field (4A) of approximately 10 acres bordering on a large area of wasteland (approximately 100 acres). Typical poisoning cycles in 1941 and early 1942 netted a consumption of thallium-poisoned oats per acre varying from 13 to 16 ounces. During one round of this field in May 1941, including a forest trail bordering it, 32 pounds of poisoned oats were eaten from 123 stations or .26 pound per station. When this consumption is distributed among the 10 acres of cane being protected we have the unusual figures of 51 ounces per acre, representing 250 to 300 rats killed per acre of cane from one poisoned bait application. This is the highest record we have obtained and serves to emphasize the magnitude of the task of protecting cane next to large waste-forest areas which are heavily infested with rats. Under such conditions serious reinfestation by rats into the cane field will occur in a very short time.

Actually at the end of the second baiting period of 6 days of Experiment No. 47, reinfestation occurred amounting to 17.6 per cent in the zinc-treated area and 15.8 per cent in the thallium-treated area. In most cane areas only two to five per cent reinfestation or return consumption would be expected.

Unfortunately, also, as soon as the forest trail became somewhat distant from the field road and the traveling more difficult, the rat-control gang had spaced the stations further apart (to save labor) than the 20 paces we had recommended for wasteland trails. This wider spacing occurred where rats were more numerous than at any place in the cane field. With these wide gaps between stations it was impossible to catch all of the rats that would infiltrate such a thin line of defense.

The day poisoned bait was applied, the unpoisoned oats in all 62 stations in Experiment 47 (zinc phosphide) had been entirely consumed. Some stations appeared to have been empty for several nights and had probably ceased to operate as feeding centers. There were fewer rats in the Experiment 48 (thallium sulphate) area, so there were relatively few empty pans at poisoning time.

Even under these conditions the relative acceptance of both poisoned baits compared with their respective unpoisoned consumption was almost identical (i.e., 18.8 per cent vs. 18.6 per cent for the first poisoning and 5.8 per cent vs. 3.9 per cent respectively for the second poisoning (see Fig. 64).

During the poisoning period the measurements of the consumption of zinc-treated oats and thallium-treated oats also show a close resemblance. The important characteristic of all prebaiting work, that of the high consumption which occurs on the first night of poisoning after baiting, is again demonstrated.

Of the total poisoned-bait consumed, 82.5 per cent of the zinc-treated and 85.7 per cent of the thallium-treated oats were eaten during the first night. The second night accounted for 11.5 per cent and 11.7 per cent, while on the third and fourth nights together, the rats ate 6 per cent and 2.6 per cent respectively of two types of poisoned oats. This is presented graphically in Fig. 65.

All of these data indicate that zinc phosphide is fully comparable to thallium sulphate in both acceptance and lethal power for the field control of rats.

The second baiting and poisoning revealed that there was a heavy reinfestation into both areas during a period of 16 days. Many rats were coming from the forest into the cane at this time and this made active baiting and poisoning necessary along

the field borders. The amount of zinc-poisoned oats accepted during the second round of poisoning was 32.8 per cent as much as the unpoisoned oats eaten in the previous six days. This is a much higher percentage than for the original poisoning, indicating no hesitancy whatever in accepting zinc-poisoned oats. An indication of the rapid action of the zinc poison was seen by the fact that dead rats were observed along the path treated with zinc phosphide the first morning after its initial exposure. An inspection on the third morning after poisoning showed three times as many "smells" or dead rats noted on the zinc-treated paths as on the thallium-treated paths. The fact that more dead rats were found where zinc phosphide was used than where thallium sulphate was used is likely due to the quicker action of the zinc phosphide, as rats die from 6 to 8 hours after eating zinc phosphide compared with from 30 to 40 hours after eating thallium sulphate.

At Waimanalo Sugar Company, Oahu, another test (Experiment 50—October 1942) was installed to continue the study of the acceptance and effectiveness of zinc phosphide when applied to rolled oats. This test differed from the former test in that zinc phosphide and thallium sulphate were used in separate and alternating groups of from 4 to 11 stations each, all in the same field. These groups of stations were placed (1) in cane, (2) along two edges of a reservoir, and (3) in heavy panicum grass areas adjacent to cane, representing three distinct types of rat harborage.

All 42 stations were baited with unpoisoned oats for a period of six days to obtain a basic consumption figure in each of the three areas. On the day of poisoning each group was divided into two parts. One half of the stations received thallium-treated oats and the other half received zinc-treated oats. The concentration of both poisons was 1–200 and corn oil was used as the attractant. The poisoned oats
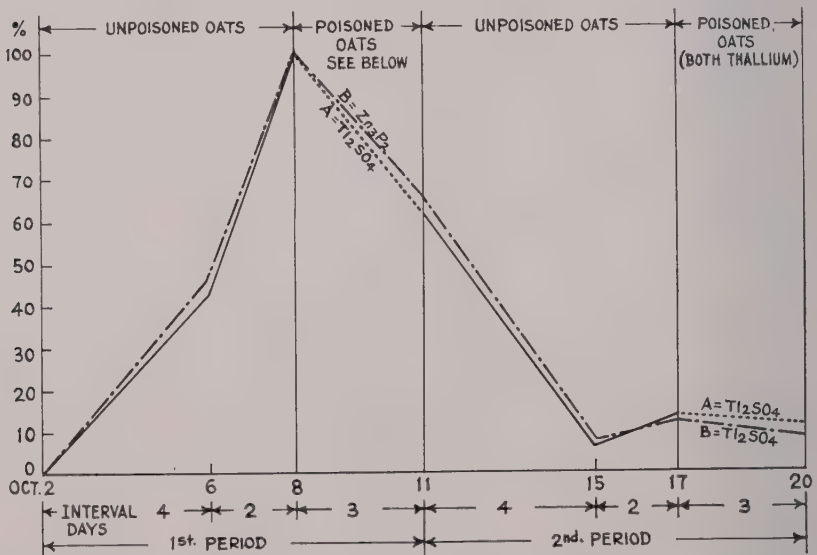

Fig. 66. The average daily consumption of unpoisoned oats, thallium-poisoned oats, and zinc-poisoned oats expressed in per cent of the best two days' consumption just previous to poisoning (from Table XXXIX).

were prepared exactly as in the previous test. After the period of poisoning a second baiting period was followed by thallium-poisoned oats only (October 11 to October 20, 1942) to catch any migrants or rats which had refused the bait at the first poisoning.

The detailed consumption data were tabulated and summarized. The summarized data are presented in Table XXXIX and part of these data are illustrated in Figs. 66 and 67.

TABLE XXXIX

SUMMARIZED DATA FROM EXPERIMENT 50 EVALUATING THE KILLING POWER OF THALLIUM SULPHATE AND ZINC PHOSPHIDE IN ROLLED OATS

A—Thallium Sulphate Only

	First period		Poisoned	Second period		Poisoned
	Unpoisoned			Unpoisoned		
Interval (days)	4	2	3	4	2	3
No. of active stations	21	21	21	11	12	16
Oats eaten (grams)	2171.6	2519.7	783.6	305	345.9	140.6
Total oats eaten (grams).........	......	4691.3	783.6	......	650.9	140.6
Avg. consumption per day (grams)	542.9	1259.9	......	76.3	172.9	......
Consumption—% of highest 2 days	43.1	100.0	62.2	6.1	13.7	11.2
Consumption—% of first baiting ..	......	100	16.7	......	13.9	3.0
Consumption—% of second baiting	......	......	......	......	100	21.6
Ratio: poisoned to unpoisoned oats		1:6.0			1:4.6	

B—Zinc Phosphide Followed by Thallium Sulphate as Check

|	First period		Poisoned zinc	Second period		Poisoned thallium
	Unpoisoned			Unpoisoned		
Interval (days)	4	2	3	4	2	3
No. of active stations	21	21	21	11	10	13
Oats eaten (grams)	2262.3	2434.1	806.3	360.7	305.8	103.9
Total oats eaten (grams).........	......	4696.4	806.3	......	666.5	103.9
Avg. consumption per day (grams)	565.6	1217.1	......	90.2	152.9	......
Consumption—% of highest 2 days	46.5	100	66.2	7.4	12.6	8.5
Consumption—% of first baiting ..	......	100	17.2	......	14.2	2.2
Consumption—% of second baiting	......	......	......	......	100	15.6
Ratio: poisoned to unpoisoned oats		1:5.8			1:6.4	
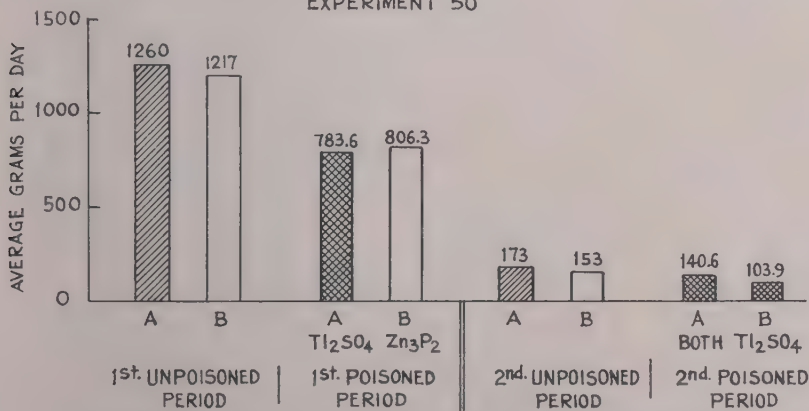
Fig. 67. Graphic presentation of the average total consumption, in grams, per day of unpoisoned oats. thallium-poisoned oats, and zinc-poisoned oats during two successive periods (from Table XXXIX).

The total unpoisoned oats consumption of all of the stations in the "A" (thallium) group was practically identical with the "B" (zinc) group. The totals were 4691 grams, for the "A" group and 4696.4 grams for the "B" group. This established a base for consumption which indicated that the rat population of the area was about equally divided between the two groups of stations.

The acceptance of thallium-poisoned oats was 62.2 per cent and zinc-poisoned oats was 66.2 per cent as much as the average of the two best days' consumption of unpoisoned oats from their respective areas. This indicated a very slight amount in favor of the zinc-treated oats. On the basis of the ratio of the poisoned oats in each treatment to the unpoisoned oats eaten in six days the percentage for thallium-poisoned oats was 16.7 per cent and for zinc-poisoned oats 17.2 per cent. These differences are so small as to be within experimental error. Therefore the two poisons have been accepted equally well.

The question of the relative effectiveness in killing the rats in the field was studied next by comparing the relative amounts of return consumption of unpoisoned grain following each kind of poison. Some reinfestation was expected because the test did not cover the entire area, leaving some favorable harborage untreated. The actual reinfestation or total return consumption was 14.2 per cent for the zinc phosphide and 13.9 per cent for the thallium sulphate. Again these differences are not significant so we must conclude that both poisons killed the rats equally well under field conditions.

The final poisoning was done by thallium sulphate applied uniformly to all groups and showed only chance differences as before.

A Study of the Efficiency of Zinc Phosphide Compared with Thallium Sulphate When the Two Are Exposed at the Same Time in Immediately Adjacent Pans: Two field experiments were conducted to test these two poisons. In former tests (Experiments 47, 48, and 50) the stations containing zinc-poisoned oats were widely separated from stations filled with thallium-poisoned oats. Therefore no' choice between the two poisons was possible. However, under the present plan, the rats were allowed to choose the poisoned mixture they preferred. The first experiment (Experiment 49—Kaeleku Sugar Company, June 1942) was conducted in and around a field of six-month-old POJ 2878 cane. The feeding stations (28 pairs) were spaced 20 paces apart along the edge of the cane field and bordering a small gulch containing excellent rat harborage. These stations had been placed and baited with unpoisoned oats for seven days by the plantation rat-control gang. The preparation and distribution of the poisoned bait was carried out by the writer aided by plantation personnel. A concentration of 1–200 was used for both poisoned baits. They were slightly oiled with "Above Par" brand of salad oil, as all other oil supplies had been exhausted at Kaeleku. The zinc phosphide powder was first added to the oil, and then the mixture was sprinkled* on and mixed with the dry rolled oats. Oil was used at the rate of 1 quart† to 20–25 pounds of dry grain.

*A good sprinkler for handling small quantities can be made by carefully drilling small holes (size No. 52 to 58, Starrett Drill & Wire gauge) in the flat tin cover of a quart mayonnaise jar. To use the jar as a sprinkling can, turn it upside down and shake it up and down as the mixture of oil and zinc phosphide runs out. A very thorough mixing of the oats is necessary.

†We have evidence that less oil may be used and yet obtain a satisfactory and even mixture. A mixture of three quarts of oil per 100 pounds of rolled oats has given very satisfactory results on a field scale at Kaeleku Sugar Company and is now believed to be sufficient.

On the day poisoned bait was placed in the two pans at the paired stations, one pan contained a measured amount of oats treated with zinc phosphide and the other contained the same amount of oats poisoned with thallium sulphate.

The detailed consumption data were tabulated and summarized in Table XL and some of these data are illustrated in Fig. 68.

TABLE XL

SUMMARY OF RESULTS COMPARING ZINC PHOSPHIDE AND THALLIUM SUL-
PHATE AS LETHAL AGENTS IN ROLLED OATS USING THE PREBAITED FEED-
ING-STATION SYSTEM

	Un-poisoned	Poisoned first night		Poisoned 2 & 3 nights		Total poisoned	
		Zinc	Thallium	Zinc	Thallium	Zinc	Thallium
Interval (days)	7	1	1	2	2	3	3
No. of active stations.........	28–28	28	28	10	5	....	....
Oats eaten (grams)	11,794	1441.3	1034.2	90.7	30.6	1532	1065
Total oats eaten (grams)......	....	....	2475.5	....	121.3	....	2597
Consumption—% of baiting ...	....	....	21.0	....	1.0	....	22.0
Difference (grams)	....	+407	....	+60	....	+467	....
Difference (%)	....	+39.4	....	+196.1	....	+43.8	....
Significance of difference	....	....	....	....	....	High	....
Odds by Student's Method.....	....	....	....	....	....	592:1	....
Avg. oats eaten per sta. (grams)	421.2	51.5	36.9	3.2	1.1	54.7	38.0
Ratio: poisoned to unpoisoned oats 1:5							
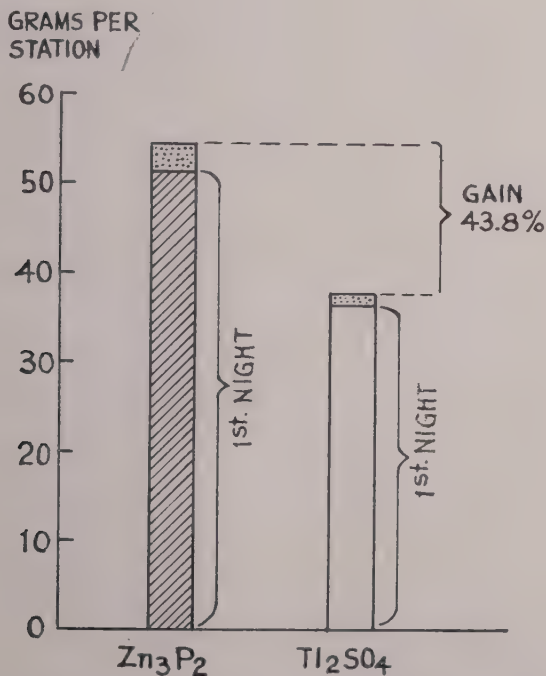
Fig. 68. Graphic presentation of the average consumption, in grams, per station of zinc-poisoned oats and thallium-poisoned oats during three nights of exposure in adjacent pans followed by a period of unpoisoned oats (from Table XL).

The second test (Experiment 51) under similar conditions was made at Waimanalo Sugar Company, October 1942. The consumption of unpoisoned oats was measured and recorded by stations (26 pairs) for a six-day period of baiting. Only two stations were entirely empty on the day poisoned bait was applied so the unpoisoned oats consumption figures form a reliable base line of 100 per cent by which to judge the poisoned oats consumption that followed. The baits were prepared exactly as described for Experiment 49 except "Mazola" salad oil was used in place of "Above Par" salad oil as the attractant and carrier of the zinc phosphide. The day poisoned bait was exposed, the two kinds of poisoned oats were distributed to the two pans at each feeding place. The detailed consumption data were tabulated and the summarized data are presented in Table XLI with some data illustrated in Fig. 69.

TABLE XLI

SUMMARY OF RESULTS COMPARING ZINC PHOSPHIDE AND THALLIUM SULPHATE ᵃ LETHAL AGENTS IN ROLLED OATS USING THE PREBAITED FEEDING-STATION SYSTᴱᴹ

| | First period | | | | | | Second period | | | |
| | Unpoisoned | | | | Poisoned | | Unpoisoned only | | | |
	"T"	"Z"	"T"	"Z"	"T"	"Z"	"T"	"Z"	"T"	"Z"
Interval (days)	4	4	2	2	3	3	4	4	2	[cut]
No. of active stations......	23	23	26	26	26	26	13	14	16	[cut]
Oats eaten (grams)	1160.1	1287.1	1671.5	1616	569	567	316.4	293.7	365	319[cut]
Differences (grams)	....	+127	+55.5	....	+2	....	+28.2	....	+45.2	[cut]
Significance of difference ..	....	None	None	....	None	....	None	....	None	[cut]
Total "T" plus "Z"........	....	2407.2	....	3287.5	....	....	....	610.1	....	68[cut]
Total oats eaten (grams) ..	....	....	....	5694.7	....	1136	....	....	....	129[cut]
Consumption—% of first baiting	....	....	....	100	....	19.9	....	....	....	2[cut]
Avg. oats eaten per day (grams) (see Fig. 69)...	290	321.8	835.75	808	....	....	52.7	48.95	182.5	[cut]
Ratio: poisoned to unpoisoned oats 1:5										

"T"—Indicates pans that were baited with thallium-treated oats during the poisoning period.
"Z"—Indicates pans that were baited with zinc-treated oats during the poisoning period.

TABLE XLII

TOTAL CONSUMPTION OF BAIT IN GRAMS AT THE "T" AND "Z" PANS FOR 26-PAIRED STATIONS

| | First period | | Second period |
	Unpoisoned 6 days	Poisoned 3 days	Unpoisoned only 6 days
"T"	2831.5	569	681.4
"Z"	2903.1	567	613.5
Difference (grams)	+71.6 ("Z")	−2 ("Z")	−67.9 ("Z")
Difference (%)	+2.4 ("Z")	−0.35 ("Z")	−11.0 ("Z")
Significance of difference...	None	None	None

The results of these tests are of special interest because they demonstrate that rats accept zinc phosphide as well as or better than thallium sulphate even when the two poisons are exposed in adjacent pans. In the Kaeleku test (Experiment 49) the acceptance of zinc phosphide showed a highly significant gain of 44 per cent over thallium sulphate. A station-to-station comparison of 28 pans indicated that 20 favored zinc phosphide, 6 favored thallium sulphate and 2 were even.

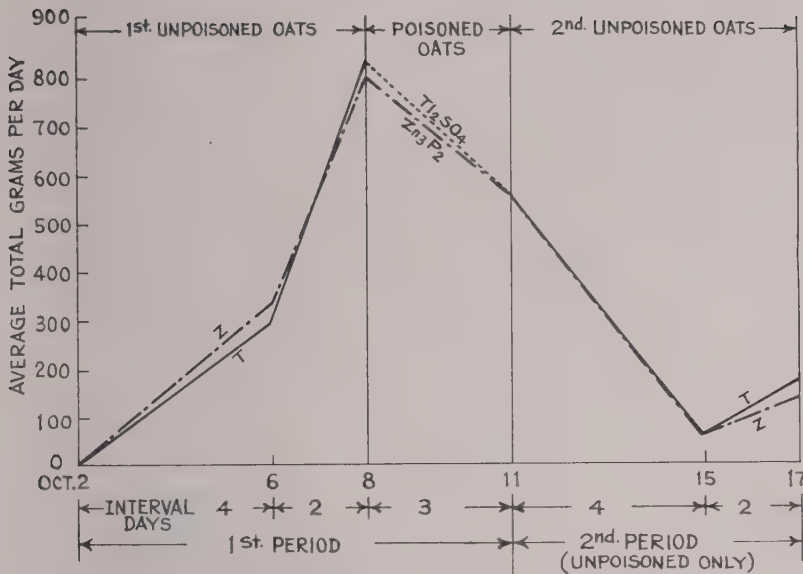At Waimanalo (Experiment 51), however, there was no significant difference

EXPERIMENT 51

Fig. 69. The average total consumption, in grams per day, of unpoisoned oats, thallium-poisoned oats, and zinc-poisoned oats during the first period of feeding in adjacent pans (from Table XLI, last line).

between the acceptance of zinc phosphide and thallium sulphate, and a station-to-station comparison made from 26 pairs indicated that 9 favored zinc phosphide, 10 favored thallium sulphate and 7 were even.

The cause of the special attractiveness of zinc phosphide at Kaeleku is not evident. There was a high percentage of *R. hawaiiensis* in the rat population at Kaeleku, but this is not believed to be sufficient reason to explain why zinc phosphide was accepted so much better than thallium sulphate at Kaeleku (Experiment 49) while it only equalled thallium sulphate at Waimanalo Sugar Company (Experiment 51).

The acceptance of both poisoned baits was satisfactory in the two experiments, resulting in a normal 1:5 ratio of poisoned to unpoisoned bait when the latter had been offered for 6 days.

These tests demonstrate that zinc phosphide is accepted fully as well as thallium sulphate. Moreover we have ample proof that the zinc phosphide was lethal, for many dead rats were seen along the trails the day following the poisoned bait distribution; thallium-poisoned rats are generally not found dead before the second day after the distribution of poisoned bait.

Prevention of the Deterioration of Zinc Phosphide: A large-scale rat-poisoning program on sugar plantations using zinc phosphide can be as successful as any that can be conducted by using thallium sulphate, provided, of course, that the technic is modified to fit the characteristics of this less familiar chemical.

The effectiveness of this chemical is entirely due to its property of generating the obnoxious* and highly poisonous phosphine gas in the presence of free acid

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*"Offensive garlic-like odor"—from Chemical Encyclopaedia by Kingzett, page 758.

and moisture. It has a somewhat sweetish taste apparently not distasteful to rats. When ingested by any animal the moisture and acidity present in the digestive tract cause the zinc phosphide to decompose with the immediate evolution of the poisonous gas that produces deadly results. Its probable reaction in the stomach is indicated by the equation:

$$\text{Zn}_3\text{P}_2 + 6\,\text{HCl} = \underset{\substack{\text{Poison}\\ \text{Gas}\\ \text{``Phosphine''}}}{2\,\text{PH}_3} + \underset{\substack{\text{A caustic}\\ \text{astringent}}}{3\,\text{Zn Cl}_2}$$
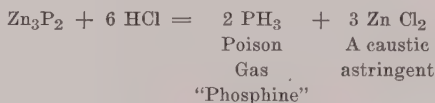
Wet baits made with zinc phosphide will deteriorate rapidly, and soon become non-poisonous. Dry baits exposed to rain will also lose their effectiveness rapidly. This is an advantage in livestock areas because any old zinc phosphide bait accidently left in the field will be less dangerous to stock as it ages. However, it is doubtful if the zinc phosphide will deteriorate any faster than the oats will sour or mold from moisture alone.

Elmore and Roth (27, p. 564) found that a ". . . prepared bait was reduced from an original analysis of 0.21 per cent of zinc phosphide to 0.14 per cent after 2 days' exposure to heavy rains."

However, dry oats bait made with zinc phosphide will remain effective for a long time, provided it is kept dry. In the original study of zinc phosphide, corn-oiled rolled oats poisoned with zinc phosphide were kept in the laboratory both in an open pan and in a closed jar for over one year. Samples from these supplies which were fed to rats at irregular intervals during this period never lost their deadly effectiveness.

Recent analyses made by Elmore and Roth (27, pp. 563, 564) at 30-day intervals up to 180 days of zinc-treated grains under conditions of ordinary storage indicated that:

The zinc phosphide content remained constant throughout the entire period.

Another sample, the original analysis of which was 0.50 per cent of zinc phosphide, was exposed to outside conditions but protected from rains. After one month the analysis showed 0.47 per cent, . . .

In general, it may be concluded that there is practically no chemical change in zinc phosphide on poisoned grains under conditions of storage but in field use some deterioration of baits may be expected, . . .

However, when a vegetable oil was used as the poison carrier and attractant, a slight odor of phosphine gas could be detected whenever a closed container of zinc phosphide was opened. During the preliminary experimental work this slight odor of phosphine caused no measurable deleterious effect on acceptance by the rats or discomfort to the operator. However, no sooner had the zinc phosphide been introduced on the plantations on a field scale then complaints began to come in from the fieldmen concerning the obnoxious odor of the phosphine gas. One man claimed that it gave him a headache whenever he picked up the leftover zinc-treated bait.

The uneaten zinc-poisoned oats that were returned from the field smelled very bad especially if they were held in a bag or bucket for a few hours or overnight in the rat-poison supply house. This obnoxious smell may account for some instances of reduced acceptance of poisoned bait by rats in the field.

The development of rancidity in these vegetable oils produced a marked acidity which in turn resulted in the decomposition of the zinc phosphide and the subsequent liberation of phosphine gas. This process was undoubtedly accelerated when the

oils soaked into the rolled oats, because of the vastly increased surface area exposed to oxidation.

However, the use of at least a small amount of some oils is considered essential as a carrier of the powdered zinc phosphide to protect the operators who mix and distribute the poisoned bait. The oil also insures good adherence of the poison to the grain and minimizes the possibility of an uneven distribution of the zinc phosphide throughout the rolled oats.

Corn oil, "Above Par" oil, raw linseed oil, coconut oil, and white neutral mineral oil have been studied in various combinations with zinc phosphide in rolled oats both in the laboratory and in the cane field at Kailua substation and at Kaeleku Sugar Company. Baits containing corn oil and "Above Par" oil as carriers for zinc phosphide powder in rolled oats continued in good condition, with only faint indications of evolution of phosphine gas, up to actual spoilage of the grain, even in very humid conditions.

Baits containing raw linseed oil in rolled oats under the same conditions as above soon began to give off objectionable and serious (poisonous) amounts of phosphine gas which was very obnoxious to all who examined these samples. This gas was most noticeable when the sample was damp. The evolution of gas appeared to stop completely after the grain was thoroughly dried.

More phosphine gas developed in bait containing crude coconut oil than linseed oil under identical conditions of exposure. Phosphine gas was detected in sample mixtures of coconut oil and zinc phosphide in rolled oats after 3 or 4 days even though they had been held in the laboratory away from any excessive moisture. Damp coconut oil mixtures deteriorated very quickly. It also seems reasonable that the presence of this odor would decrease field acceptance by rats.

Baits made with white neutral mineral oil mixed with zinc phosphide in rolled oats did not develop any odor whatever under very humid conditions in the field. This gave further evidence that moisture alone without rancidity does not cause the noticeable evolution of phosphine gas.

If we are to continue to use vegetable oils as attractants or even merely as carriers of the zinc phosphide in dry rolled oats, it becomes necessary to find means to prevent the development of rancidity in these oils with the subsequent deterioration of the poison, or else use an oil which cannot become rancid, such as a neutral mineral oil.

The deterioration of zinc phosphide in orchard-mouse baits was checked by the Wildlife Research Laboratory of the Department of Interior by adding 5 grams of magnesium carbonate to 10 grams of zinc phosphide to treat 10 quarts of diced fresh apple.*

We have successfully coated diced fresh-cut coconut with mill lime (calcium hydroxide) and zinc phosphide in the same manner, as was done with apples referred to above, and found this bait very acceptable and effective.

The fresh coconut should be cut into approximately half-inch cubes. Our work to date indicates that zinc phosphide and mill lime $Ca(OH)_2$ added together at the rate of 0.33 per cent of the former and 0.25 to 0.33 per cent of the latter, by weight,

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*Letter from Justus C. Ward, pharmacologist, Wildlife Research Laboratory at Denver Col., to author dated March 19, 1942.

A formula is given also by F. E. Garlough on page 11 of "Conservation Bulletin No. 36," U. S. Department of the Interior Fish and Wildlife Service.

are satisfactory proportions. The larger the pieces of coconut, the lower the concentrations of zinc phosphide and mill lime must be, or else the coating of these materials on the surface of the pieces of coconut will become too heavy for ready acceptance of the bait. Since rats must, of necessity, chew the corners and edges of the coconut cubes first, they eat a large proportion of the poison with the first few bites of the coconut. This poisoned coconut bait is prepared by placing all of the materials in a closed container and shaking vigorously for several minutes. This shaking process bruises the fresh coconut cubes and brings the oil to the surface where it mixes with the powdered zinc phosphide and lime and causes them to adhere to the cubes. If this bait is to be used immediately after mixing, it must be protected from rain. However, two or three hours of drying in the sun will increase its usefulness by causing the lime and zinc phosphide coating to harden, forming a protective crust which resists rain and handling to a remarkable degree.

Another method of solving the problem of the deterioration of the vegetable oils is to add a stabilizing agent to the oil itself before it is mixed with any other material. Dr. Hance believes that gum benzoin will successfully prevent vegetable oils like crude coconut oil from becoming rancid, without reducing its palatability and acceptability to rats.

However, as hydrated lime is always available and cheap, if acceptable to rats, it offers a quick and simple solution; so we have carried out several field trials with amounts of mill lime varying from ¼ of 1 per cent to 2 per cent by weight, with ½ per cent zinc phosphide in rolled oats. Amounts of lime from ¼ to ½ of 1 per cent have kept zinc phosphide with raw linseed oil in rolled oats in good condition even in a damp environment.

Coconut oil and zinc phosphide in rolled oats will deteriorate in the presence of ¼ of 1 per cent of lime even in the comparatively dry laboratory, while ½ of 1 per cent has not been always entirely satisfactory in the field. Corn oil mixed with zinc phosphide in rolled oats developed only a slight odor when kept in a closed container, indicating it to be the most stable of the vegetable oils under trial. A small amount of lime added to this oil mixture would insure against deterioration. In actual plantation practice at Kaeleku Sugar Company, ¼ of 1 per cent of lime is added to maintain the sweet condition of the oats even after they are very damp.

Neutral white mineral oil has no tendency to become acid and therefore needs no neutralizing agent.

Field Experiments in Acceptance of Mill Lime: It was now important to discover how much lime could be added to the zinc phosphide and oiled-oats mixture before the rats would seriously discriminate against the lime-fortified bait. The first test (Experiment 54, Kaeleku Sugar Company, March 1943) compared raw linseed oil alone with raw linseed oil plus ½ of 1 per cent of mill lime. The area chosen for this test was a forest trail 200–300 feet from the edge of cane (Field 21) and a trail along the edge of cane bordering a forest area, the forest trail having by far the greater number of rats.

The bait was prepared by mixing raw linseed oil into the rolled oats at the rate of one quart of oil to 25 pounds of the oats (40 cc. per pound). The poisoned bait was prepared by first stirring the zinc phosphide into the raw linseed oil, and then the mixture added to and stirred into the rolled oats. Lime was added to the oil with the zinc phosphide for the lime-treated bait. The concentration of zinc phosphide was 1–200 in both mixtures.

The stations were grouped in pairs (50) along the forest trails and cane borders approximately 60 feet apart with the individual stations of each pair immediately adjacent. The stations were baited for five days, then poisoned for three days. The consumption of unpoisoned oats was measured and recorded after the third and fifth night followed by one measurement of poisoned oats after the third night of exposure.

The detailed consumption of the raw linseed-oil-treated unpoisoned oats, and the raw linseed-oil-treated poisoned oats with and without lime was tabulated and summarized in Table XLIII and partially illustrated in Fig. 70.

TABLE XLIII

SUMMARY OF RESULTS COMPARING LIME VERSUS NO-LIME IN
RAW LINSEED OIL-TREATED OATS

	Unpoisoned period				Totals		Poisoned period zinc phosphide	
	Odd	Even	Odd	Even	Odd	Even	Odd*	Even† +lime
Interval (days)	2	3	2	2	5	5	3	3
No. of active stations............	32	31	46	43	46	43	48	46
Oats eaten (grams)	1600.0	1435.6	3002.8	2841.8	4602.9	4277.3	882.3	770.0
Differences (grams)	....	−164.4	....	−161.0	....	−325.5	....	−112.3
Differences (%)	....	−10.3	....	−5.4	....	−7.1	....	−12.7
Total oats eaten (grams)........	....	3035.6	....	5844.6	....	8880.2	....	1652.3
Consumption—% of baiting	....	34.2	....	65.8	....	100	....	18.6
Avg. oats eaten per day (grams) (see Fig. 70)	533.0	478.5	1501.4	1420.9	....	....	....	....
Consumption—% of highest 2 days	35.5	33.7	100	100	....	....	58.8	54.2
Ratio: poisoned to unpoisoned oats 1:5.4								

*Odd-numbered station of pair received raw linseed oil only during poisoning period.
†Even-numbered station of pair received raw linseed oil plus ½% lime during poisoning period.
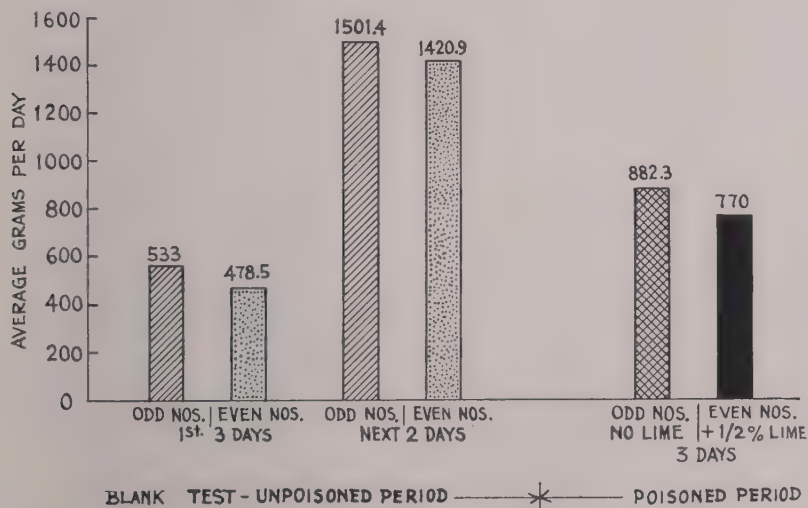
Fig. 70. Graphic presentation of the average total consumption at fifty pairs of feeding stations, in grams per day, of unpoisoned oats, followed by zinc-poisoned oats treated with raw linseed oil for the purpose of comparing ½ per cent lime (even-numbered stations) versus no lime (odd-numbered stations) (from Table XLIII).

The population of rats along the forest trail adjacent to Field 21 was sufficiently high to obtain reliable comparisons. The apparent loss of 12.7 per cent due to the use of ½ per cent lime (even-numbered stations) is not statistically significant (odds 14:1) especially when we consider that the chance variation of the paired stations favoring the odd numbers was 7 per cent before the differential treatment had been applied, leaving only a possible 5.7 per cent that could be due to treatment.

The station-to-station comparison showed that chance variations favored the odd-numbered stations 22 times and the even numbered stations 19 times. When ½ per cent of lime was added the comparisons favored no lime (odd numbers) in 25 cases with only 12 cases favoring the ½ per cent lime leaving 13 stations even.

These data indicate that the rats did not discriminate against the ½ per cent lime in any serious degree in this test. However, it is highly probable that ½ per cent lime represents about the upper limit of acceptance by rats and that any further increase in the lime content would be followed by definite discrimination.

In every experiment using zinc phosphide we took advantage of all opportunities to study the acceptance and efficiency of this poison. The last four lines of Table XLIII were added for this purpose.

The acceptance of 18.6 per cent as much zinc-poisoned oats as unpoisoned oats (ratio 1:5.4) in a five-day baiting period is quite normal when compared with previous tests using thallium sulphate.

The consumption of zinc-poisoned oats was 58.8 per cent for the no-lime and 54.2 per cent for the ½ per cent lime stations of the best single day of baiting (see last line of Table XLIII). These percentages also represent a satisfactory acceptance of zinc phosphide when compared with previous records of acceptance of thallium sulphate. They are better than the percentages obtained in Experiment 53 (*i.e.*, 50.7 per cent and 52.6 per cent).

There was no significance to the decreased acceptance of the lime-treated poisoned oats over the untreated poisoned oats. There was an indication that ½ per cent lime approached the limit of concentration above which a definite discrimination against the lime-treated poisoned oats would be expected.

Field observations of a small number of stations in a skirmish test at Kailua Substation indicated that rats discriminated heavily against two per cent limed zinc-treated oats, but on the other hand some lime was more acceptable than rancid oiled oats which gave off the strong odor of phosphine gas.

Crude coconut oil is known to become rancid more readily than any of the other vegetable oils used in rat control. The second field experiment (Experiment 55, April 1943) in the use of lime in the oiled zinc-treated oats compared crude coconut oil carrying one-half per cent lime with coconut oil without the lime. The test was conducted at Kaeleku Sugar Company along a plantation railroad track that passed through a forest area and an abandoned cane field. Rats were in sufficient number in this area to give high consumption figures.

The unpoisoned bait was prepared by mixing coconut oil into the rolled oats at the rate of one quart of oil to 25 pounds of the oats (40 cc. per pound). The poisoned bait was prepared by first stirring the zinc phosphide into the crude coconut oil, and then the mixture added to and stirred into the rolled oats. Lime was added to the oil with the zinc phosphide to make the lime-treated bait. The concen-

tration of the zinc phosphide was 1 to 200 in both mixtures, the same as for Experiment 54.

Fifty pairs of stations were placed approximately 60 feet apart with the individual stations of each pair immediately adjacent. The stations were baited for six days, then poisoned four days. The consumption of unpoisoned oats was measured and recorded after the third and sixth night followed by two measurements of the poisoned oats, the first after one night of exposure and the second after the fourth night when the pans were picked up.

The detailed consumption of the crude coconut oil-treated unpoisoned oats and the crude coconut oil-treated poisoned oats with and without lime were tabulated and summarized in Table XLIV, with some of these data illustrated in Fig. 71.

TABLE XLIV

SUMMARY OF RESULTS COMPARING LIME VERSUS NO-LIME IN
COCONUT OIL-TREATED OATS

| | | Unpoisoned period | | | | Total | |
		Odd	Even	Odd	Even	Odd	Even
(1)	Interval (days)	3	3	3	3	6	6
(2)	No. of active stations...........	14	19	48	48	48	49
(3)	Oats eaten (grams)	1049	1486	5084	4880	6133	6366
(4)	Differences (grams)	....	+436.6	....	—204.1	....	+233.6
(5)	Differences (%)	....	+41.6	....	—4.0	....	+3.8
(6)	Total oats eaten (grams).........	....	2534.4	....	9963.3	....	12499.0
(7)	Consumption—% of baiting	....	20.3	....	79.7	....	100
(8)	Avg. oats eaten per day (grams) (see Fig. 71)	349.6	495.2	1694.6	1626.5	....	....
(9)	Consumption—% of highest 3 days	20.6	30.4	100	100	....	....

| | Poisoned period (zinc phosphide) | | | | Total | |
	Odd*	Even† +lime	Odd*	Even† +lime	Odd*	Even† +lime
(1)	1	1	3	3	4	4
(2)	46	41	17	19	47	45
(3)	1012.7	1181	125	90	1137	1270
(4)	....	+167.8	....	—35.1	....	+132.7
(5)	....	+16.6	....	—28.1	....	+11.7
(6)	....	2193.2	....	214.3	....	2407.5
(7)	....	....	....	....	....	19.3
(8)	....	....	....	....	1137.4	1270.1
(9)	....	....	....	....	67.1	78.1

Ratio: poisoned to unpoisoned oats 1:5.2

*Odd-numbered station of pair received coconut oil only during poisoning period.
†Even-numbered station of pair received coconut oil plus ½% lime during poisoning period.

During the baiting period the even-numbered stations averaged 3.8 per cent heavier consumption than the odd-numbered stations. This variation was the result of pure chance. When poisoned oats treated with ½ per cent mill lime were placed in these same stations (even numbers) they showed an increase in consumption up to 11.7 per cent over their no-lime counterparts (see Table XLIV). However, a statistical analysis by Student's method showed that there was no significance to this gain. Student's odds were very low (5:1) indicating this to be largely the results of chance.

A station-to-station comparison also indicated no significance to these differ-

ences. Out of 50 pairs, 20 favored no lime (odd numbers) while 22 favored ½ per cent lime (even numbers) and 8 pairs were evenly matched. This differs only slightly from the distribution during the baiting period, when 15 favored the odd-numbered stations, 17 favored the even-numbered stations and 18 were even.

But these results do tell us that *the rats will readily accept ½ per cent of lime in coconut oil* and in some instances appear to like it better than plain coconut oil. Since this bait was made up fresh, no deterioration could have taken place until after most of the rats had eaten all they wanted on the first night. After the fourth night, when the left-over poisoned grain was picked up, a distinct odor of phosphine gas had had time to develop in the unlimed bait. It is highly probable that some lime in the bait is less objectionable to rats than any odor of phosphine, which may develop in the coconut oil mixtures with age and exposure to moisture.

The amount of acidity that was present in several coconut-oiled-oats combinations before and after exposure in the field was determined* in the plantation laboratory using the colormetric rapid chemical method. Results are given below:

Rolled oats baits	Date put out	pH	Date picked up	pH
Coconut oil+zinc phosphide	4/15	6.2	4/19	5.9
Coconut oil+lime	4/15	8.4	4/19	6.6
Crude coconut oil alone..........		4.7		

These results clearly indicate that there is sufficient acidity in the crude coconut-oil mixtures to explain and justify the presence of phosphine gas in the unlimed zinc-poisoned bait.

EXPERIMENT 55
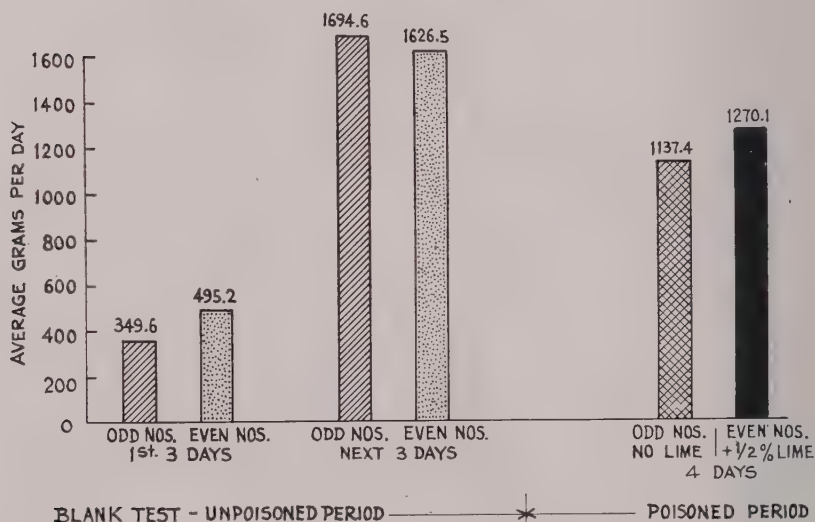
Fig. 71. Graphic presentation of the average total consumption, in grams per day of unpoisoned oats, at fifty pairs of feeding stations, followed by zinc-poisoned oats treated with coconut oil for the purpose of comparing ½ per cent lime (even-numbered stations) versus no lime (odd-numbered stations) (from Table XLIV).

*pH determinations by K. Ibara, R.C.M. analyst, Kaeleku Sugar Co.

After four days of exposure, the limed bait was still close to the neutral point and safe to handle in quantity, but a dangerous quantity of phosphine gas was being liberated from the unlimed crude coconut-oiled zinc bait. It therefore becomes important that this bait mixture be made up fresh and that surplus poisoned oats picked up from the field should not be used again.

The total acceptance of zinc-poisoned oats, whether containing ½ per cent of lime or not, was again satisfactory being 19.3 per cent (ratio 1:5.2) as much as the unpoisoned bait consumption in the six-day baiting period. The poisoned bait consumption percentages were also high, being 67.1 per cent and 78.1 per cent for the no lime and ½ per cent lime respectively, when compared with the average of the last three days of unpoisoned bait consumption. However, these figures are too high because the base of these calculations is the average for the last three days instead of the last two days as is generally used. The low average consumption of unpoisoned oats per day for the first three days, 20.6 per cent and 30.4 per cent respectively, compared with the next three days (100 per cent), demonstrates the very low consumption of oats that normally can be expected at the beginning of any baiting period. Of a total of 50 stations of each group exposed, only 14 and 19 respectively, showed any activity during the first three days. It is evident, then, that no accurate estimate of the amount of unpoisoned or poisoned oats needed for an area can be made from measurements made during the first three days.

The record of the poisoned bait consumption the first night again demonstrates the high consumption that occurs during this night compared with the following nights of the poisoning period. The totals are tabulated as follows:

CONSUMPTION OF BAIT BY NIGHTS DURING THE POISONING PERIOD

	1st night		2nd, 3rd, & 4th nights together		Totals	
	No lime	+ ½ % lime	No lime	+ ½ % lime	No lime	+ ½ % lime
Amounts (grams)	1012	1181	125	90	1137	1270
Amounts (%)	89.0	92.9	11	7.1	100	100

These data are graphically presented in Fig. 72.
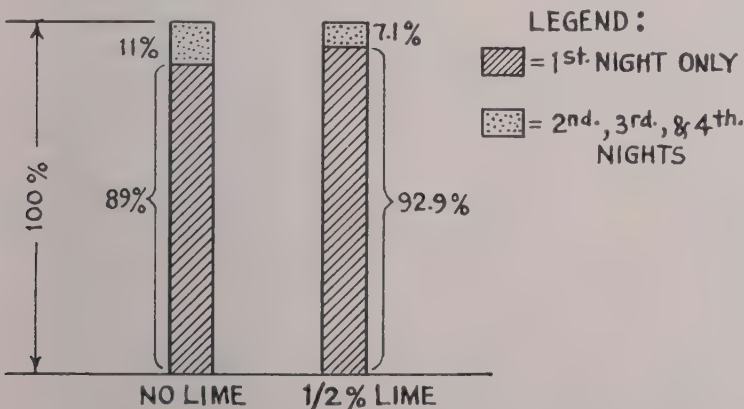
Fig. 72. A graphic presentation of the proportionate amounts of zinc-poisoned, coconut-oiled rolled oats consumed by rats during consecutive nights, expressed in per cent for the purpose of comparing ½ per cent lime with no lime.

Eighty-nine per cent of the total consumption of the no-lime poisoned bait and

92.9 per cent of the total consumption of poisoned bait containing ½ per cent lime were eaten during the first night of exposure. Only 11 per cent and 7.1 per cent respectively of the totals were eaten on the second, third, and fourth nights combined. The heavy consumption of bait during the first night of the poisoning period is again clearly indicated.

As a final comment on this test, we feel that if coconut oil must be used with zinc phosphide in rolled oats bait, *one-half per cent mill lime or other suitable alkalizing agents should be included in the formula.* This can be done without causing a decreased acceptance by field rats; it is an inefficient use of material and also dangerous to operators to attempt to use crude coconut oil in this poisoned-bait mixture on a field scale without the addition of an alkaline stabilizer, *i.e.,* mill (hydrated) lime.

A good solution of the problem of deterioration of zinc phosphide is the use of *neutral mineral oil* in the mixture in place of coconut oil. Under the title "Use of oil attractants with the prebaited feeding system," it has been demonstrated that neutral mineral oil is a satisfactory substitute for our best vegetable oil (corn oil) so there is no valid reason for delay in adopting it. Neutral mineral oil is much cheaper than any of the vegetable oils so its substitution would be an actual economy. Incidently, many pet animals become very fond of mineral oil, so why should it not be accepted by rats as well.

If it is true, as believed in some medical circles, that mineral oil is actually an intestinal irritant* causing an excessive flow of juices instead of being a lubricant, then its use with zinc phosphide might readily cause a more rapid killing action in rats, due entirely to the increased amount of acid juices present and in contact with the zinc phosphide.

The desirable aroma of corn oil in bait can be obtained by adding a small per cent of corn oil which has been treated with gum benzoin, as suggested by Dr. Hance, to the mineral oil without the use of an alkalizing agent. Further research is planned to determine the value of these procedures.

Cage Tests: The cage tests using zinc phosphide were conducted in the same manner as previously described for other poisons. The concentration of zinc phosphide in the rolled oats was 1–200. It was prepared by first mixing the zinc phosphide in corn oil and then applying the mixture to dry rolled oats and stirring thoroughly.

The results of this series of trials have been summarized and given briefly in Table XLV.

Fourteen out of a total of 31 rats which died during the zinc phosphide trials had refused or at least survived, strychnine offered 31 times and arsenic 22 times. Even with this amount of education in detecting poisons, these rats succumbed easily to the first trial using zinc phosphide. The other seventeen rats had not been offered poison previously. The average amount of zinc-poisoned oats eaten by the 31 rats was 2.5 ∓ 0.2 per cent of their body weight. By comparing this figure with the results obtained with thallium-poisoned oats (4.2 ∓ 0.2 per cent of body weight) it was found that only 59.5 per cent as much zinc-poisoned bait was accepted as thallium. This reduced consumption per unit of body weight is thought to be due almost entirely to the quicker lethal action of the zinc phosphide, which causes death

*Wood, H. C.: Therapeutics, Philadelphia, J. B. Lippincott Company, 1905, p. 674.

TABLE XLV

SUMMARY OF CAGE TESTS USING ZINC PHOSPHIDE IN ROLLED OATS (1–200)

Rat species	No. of trials	No. of rats	Avg. body wt. gms.	Unpoisoned oats eaten			Poisoned oats eaten in 3 days		
				No. of days record	Daily avg. gms.	% of body wt.	Avg. gms.	% of body wt.	% of daily avg. unpoisoned
R. norvegicus	5	5	195.3	6.8	12.8	6.8	4.5	2.5	35.7
R. r. rattus	11	11	110.2	6.6	8.9	8.1	3.2	2.7	36.0
R. r. alexandrinus	15	14	97.2	12.4	7.5	8.3	2.2	2.2	30.2
R. hawaiiensis	1	1	83.1	7	8.6	10.3	3.4	4.1	39.5
Totals	32	31	116.6	9.4	9.85	8.1∓.5	2.9	2.5∓.2	33.3∓.3.0

Remarks:

    R. norvegicus—5 died.

    R. r. rattus—11 died.

    R. r. alexandrinus—14 died, 1 refused on first offer but ate on the 2nd and died.

    R. hawaiiensis—1 died.

    Totals: 31 died 97%

               1 lived   3%

                    100%

in six to eight hours after its ingestion. The slower action of the thallium sulphate, requiring 30 to 40 hours to induce death, allows sufficient time for more than one meal of the poisoned grain. On several occasions, thallium-sick rats have been observed eating poisoned oats at feeding stations. Out of 32 trials on 31 rats there were 31 deaths. One rat refused zinc phosphide for one feeding but readily accepted the poison when it was returned to his cage following a period of unpoisoned oats. The rats that ate the zinc-poisoned bait were dead the following morning after the bait had been placed in their cages. Six exact measurements of the elapsed time after eating the poisoned bait gave an average of 7.8 hours until death.

The deaths in our cage tests must have resulted from acute poisoning, there having been no delayed action. With direct poisoning, when the poison intake may be small, a longer delay before death might be expected. In this connection, the observations of Lieutenant M. S. Johnson, U. S. Navy, are of interest. At weekly intervals, a rat was fed three sublethal doses of zinc phosphide by Lieutenant Johnson. Following the first two doses, there were apparently no untoward effects, but after eating the third portion, the rat died. A postmortem examination showed a condition similar to typical dropsy with an accumulation of fluid under the skin and extensive injury to the tubules of the kidneys. The importance of these observations lies in the fact that the rat continued to accept successive allotments of zinc-poisoned bait and that the damaging effect of successive doses on body tissues was cumulative. If such observations are substantiated by further work, they will place zinc phosphide high in the list of effective rat poisons.

Zinc phosphide was 97 per cent effective in these cage tests. It was equal to, and is the most promising substitute for, thallium sulphate as a lethal agent in dry cereal rat bait. The concentration of 1–200 was strong enough to kill promptly and surely in six to eight hours after the poisoned bait was actually eaten.

Consolidated Summary of All Data on the Poisons Studied in Cage Tests: The essential figures, compiled from the results obtained by the use of the several poisons, are brought together in Table XLVI for comparison. The poisons are

TABLE XLVI

CONSOLIDATED SUMMARY COMPARING POISONS USED IN CAGE TESTS GIVING THEIR EFFICIENCY RATING

	No. of trials	Avg. body wt. of rats grams	Avg. unpoisoned oats eaten		Avg. poisoned bait eaten		% of daily avg. un-poisoned	Results						Efficiency rating
			Grams per day	% of body wt.	Grams	% of body wt.		Deaths No.	%	Recovery No.	%	Refusals No.	%	
Thallium sulphate (1–200) in oats from Table XXIV	59	148	11.9	8.6∓.3	6.0	4.2∓.2	50.7∓2.5	57	96.6	...	...	2	3.4	Standard(1)
Zinc phosphide (1–200) in oats from Table XLV	32	116.6	9.8	8.1∓.5	2.9	2.5∓.2	33.3∓.3	31	96.3	...	...	1	3.7	1
Phosphorus paste (40%) in oats	49	129.1	9.7	8.1	4.5	3.7	50.2	36	73.5	11	22.4	2	4.1	2
Red squill powder (1–12) in oats	22	111.2	10.4	9.35	3.5	3.0	33.2	9	40.9	11	50.0	2	9.1	3
Phosphorus paste (30%) in oats	19	166.4	12.8	8.2	6.7	5.3	59.0	6	31.6	12	63.2	1	5.2	4
L-Tox-red squill (20%) in shrimp meal from Table XXXI	38	162.8	12.6	7.9	2.4	1.6	20.4	7	18.4	30	79.0	1	2.6	5
Ratmort or Rodite (red squill)	11	91.5	7.7	8.2	...	4.4	65.8	2	18.0	9	82.0	...	...	6
Arsenic mostly As$_2$O$_3$ (1–20) in oats	29	126.6	10.6	8.5	1.1	0.9	10.5	5	17.2	17*	58.7	7*	24.1	7
Strychnine (alkaloid 1–200 and 1–300) in oats from Table XXVI	37	127.8	9.6	8.0∓.3	7.5	6.6∓0.7	89.1∓12.1	4	10.8	33	89.2	...	...	8

*Due to deliberate spilling of the grain, it was impossible to determine correctly the recoveries or refusals.

arranged in descending order of efficiency using thallium sulphate as the standard. This order of efficiency applies only with the bait carrier used and no assumption is made or implied that other (meat or wet) baits would give the identical results.

These results emphasize the *superiority* of *zinc phosphide* over all competitors except *thallium sulphate*. *Phosphorous paste* (Rat-Nip) also gives rather good results when the concentration is kept above 38 per cent and the material used while fresh. All of the other poisons used with rolled oats fall so low in efficiency as to be useless in field-rat control.

The percentages of deaths, recoveries and total refusals for each poison are shown graphically in Fig. 73.
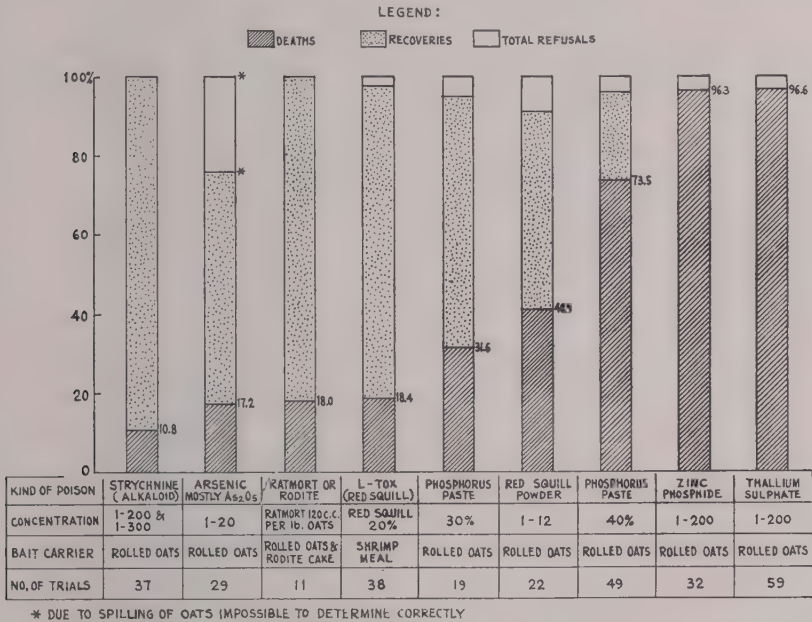
Fig. 73. Graphic presentation of the summary of feeding trials in cages showing comparative effectiveness of various poisons expressed in per cent.

Secondary Poisoning:

Secondary poisoning of domestic animals induced by their feeding on live or dead rodents which had eaten poisoned rat baits has not been given much attention in the literature. Under normal circumstances, excessively strong baits are not eaten readily by rodents, and are also objectionable from the standpoint of safety and economy.

Schlupp. (71, pp. 33–34) has cited several instances from New Zealand and South Africa where large numbers of rabbits and birds which had been killed by strychnine, and then fed to dogs and cats, resulted in only a few isolated cases of secondary poisoning.

Pemberton (60, p. 175) was unable to induce secondary poisoning by, " . . . feeding the mongoose with rats and mice which have died from eating strychnine-wheat and barium carbonate cakes."

Garlough (33, pp. 1–2) reported that, "The possibility of secondary poisoning of birds and mammals through eating carcasses of animals killed by thallium sulphate has been extensively studied at the Control Methods Research Laboratory maintained by the Bureau of Biological Survey* at Denver, Colorado. Thallium sulphate is used under certain conditions in the control of ground squirrels, prairie dogs, rats, and other rodents, and of moles. The birds and mammals studied as possible agents in secondary poisoning have been ducks, pigeons, quail, hawks, ravens, mice, white rats, brown rats, ground squirrels, prairie dogs, rabbits, porcupines, sheep, and cattle. These results of the laboratory studies and of investigations in the field have thrown sufficient light on the possibility of secondary poisoning to indicate that it would be remote."

Garlough (33, p. 2) also presented evidence to show that, " . . . if ducks, or any other birds mentioned, should eat grain poisoned with thallium sulphate exposed in rodent control, and then if these birds later should be eaten by man, the danger from secondary poisoning would be practically nil." For example, to get a lethal, " . . . dose from eating ducks that had died from thallium poisoning, [a man] would have to eat at one meal at least 45 entire ducks weighing 750 grams each (including the viscera)."

According to chemical theory, no secondary poisoning can occur when dogs or cats catch and eat rats which are sick, dying or dead from zinc phosphide poisoning. This is true because the residual products of the phosphine gas (PH_3) produced in the rodent's intestinal tract are non-poisonous.

To obtain factual evidence on this point some feeding experiments were carried out with both cats and mongooses. The concentration of zinc phosphide in the oats fed to the rats used in these tests was generally 1–100 instead of the less concentrated 1–200 commonly used in field poisoning following baiting.

In June 1942 three rats poisoned with zinc phosphide were fed, one to each of three cats. There were no visible effects on the cats. Two of these cats were young, half-grown specimens, which were kept caged for observation to make certain that they ate all of the carcasses of the rats. Also, R. Urata of our Experiment Station staff reported on November 10, 1942, that one of his cats had eaten a zinc-poisoned rat without ill effect.

Two wild mongooses (*Herpestes javanicus*) were caged and fed zinc-poisoned rats at intervals during the period between January 1 and February 8, 1943. One mongoose ate five of these rats and the other consumed seven during the observation period. The poisoned rats were fed to the mongooses at varying intervals of from an hour to six hours after the rats had eaten zinc-poisoned oats, when some of them were breathing their last. During these trials neither one of the mongooses showed any sign of ill effects from their diet of zinc-poisoned rats.

Therefore, both from the deductions of chemical theory and of practical experimental evidence, we conclude that no cases of secondary poisoning of the natural enemies of rats will occur from their eating rats poisoned by zinc-treated oats. On the other hand if thallium sulphate in a concentration of 1–200 in rolled oats had been used instead of zinc phosphide in the cage experiments discussed above, all of the cats and mongooses would have died from secondary poisoning after eating one

*Now operated under Fish and Wildlife Service, Dept. of the Interior.

or two thallium-poisoned rats. Caged rats have consistently eaten several times the minimum lethal dose* of thallium sulphate in rolled oats. This same condition undoubtedly obtains to a high degree when using the prebaited feeding-station method in the field. The slaughter of the mongoose has been terrific in cane fields since the adoption of the system of baiting followed by thallium poisoning. This animal is especially diligent in catching and eating all sick or dead rats resulting from poisoning or trapping.† Also on several occasions following a poisoning campaign at Waimanalo Sugar Company, during the time when thallium sulphate was being used exclusively in rat baits, the writer observed dead or sick cats and mongooses in the upper cane areas. While the animals were still alive they were generally so completely paralyzed in the hind quarters that both hind legs dragged on the ground in a manner characteristic of thallium sulphate poisoning. Manager W. C. Jennings has recalled to our attention the fact that after a number of years of rat poisoning with thallium sulphate at Kaeleku Sugar Company, not a single mongoose could be found on plantation cane lands at that time. He distinctly recalls that formerly the mongoose was abundant on Kaeleku Sugar Company cane lands. The only mongoose seen by the writer during an extended stay (May 1943) in that region was in the forest area far beyond the limits of the plantation.

It is an unfortunate by-product of our poison campaign that this most aggressive natural enemy of the rat should suffer so seriously. Both the mongoose and the wild domestic cat do much good work in rat control in the field, and therefore should be encouraged.

On Kauai, however, where the mongoose was never imported there has not been any noticeably harmful effects from the use of thallium sulphate except perhaps around villages and camps where a few domestic cats and dogs may have suffered from secondary poisoning.

ACCIDENTAL POISONING OF OTHER ANIMALS OR FOWLS:

Even with the extensive and continuous poisoning operations going on in the cane areas, it is only occasionally that a few chickens have been poisoned around camps where they had been allowed free range into the cane fields. This could be avoided if the chickens were penned up for the three or four days while the poisoned bait was being exposed in that immediate area. In most instances it may be prevented merely by pressing the cover of each feeding station lower and flatter, leaving only sufficient clearances for rats (1½–2 inches) between the edges of the pan and the cover.

Pheasants rarely, if ever, reach under the cover of feeding stations to eat either the unpoisoned or poisoned oats. However, it is possible to poison birds if the pan is pulled or slides out from under the cover into full view from the air. This will

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*Refer to Tables XXIV and II and Fig. 51 for amounts of bait consumed in cage tests compared with minimum lethal dose.

†At Waimanalo Sugar Company the writer found that it was practically impossible to catch and identify rat specimens caught in snap traps before the mongoose would find and eat them.

Pemberton reported in his unpublished field notes made in 1923, that he stayed an entire night in a 3-acre field (Honokaa Sugar Co., Field 26, 1923 crop Badila) to observe the feeding of rats on strychnine whole-wheat bait. Early the next morning he reported 180 dead rats observed in the area. By nine o'clock that morning the mongooses had carried away and eaten the entire kill of rats.

rarely happen if stations have been placed properly on level ground under the edge of cane or other cover. The careless throwing or spilling of poisoned grain on open ground can also result in death to doves and mynah (*Acridotheres tristis*) birds.

Some dogs have been known to eat dry rolled oats. It is possible for a hungry dog to search out enough feeding stations in a field on the first night of poisoning to obtain a lethal dose. In Experiment 25, 1936, conducted at Manoa Substation, dogs discovered and ate some experimental oiled briquettes, processed from thallium-poisoned oats, with disasterous results to three dogs. These briquettes so closely resembled dog discuits that their manufacture was immediately discontinued. However, we believe that when dogs have died, it has been due almost certainly to secondary poisoning from eating thallium-poisoned rats. With the change from thallium sulphate to zinc phosphide in the rat bait, this cause of secondary poisoning will be eliminated. If cattle are allowed access to areas being baited with rolled oats, invariably they will discover and systematically plunder a group of stations placed along a trail or road. On several occasions baiting with oats has had to be discontinued in a waste area because cows had discovered and ransacked all of the feeding stations. Since no poison had been placed in the field up to that time, no harm to the cattle resulted.

On one occasion at Kilauea Sugar Plantation, however, cows broke through their pasture fence and ranged throughout a cane field in which poisoned bait had been placed about 24 hours before. Plantation personnel were truly alarmed when they discovered that a number of stations had been cleaned out and a number of others at least upset. The cows involved in this incident were isolated for observation, but no harmful effects developed in any of this stock. It appeared that, since the rats had had several hours of darkness to visit and eat the bait on this first night of poisoning before the cattle broke through, the remaining quantity of poisoned oats in any one of the feeding stations was so small that one cow would have had to visit and eat all of the remaining poisoned oats in a large number of stations to have been poisoned, but since the total oats eaten was distributed among a number of cows in this herd, luckily, no poisoning symptoms developed.

PRECAUTIONS TO BE OBSERVED WHILE HANDLING POISONS:

In addition to the ordinary precautions for any one to observe while handling poisons, the following suggestions are emphasized for rat-poisoning work:

Arsenic, strychnine, phosphorus, thallium sulphate and zinc phosphide are deadly poisons to all animals so they must be kept out of reach of fowls, dogs, cats and other domestic animals. Special care should be observed to prevent children from coming into contact with any of these poisons.

Thallium sulphate and zinc phosphide have special characteristics that should be mentioned. Thallium sulphate may be *absorbed through the skin* so special care should be taken not to handle wet or even dry thallium sulphate bait with bare hands. Avoid breathing any of the *dust* coming *from* the dry *zinc phosphide powder* because this is the *most likely way to become accidently poisoned*. Do not attempt to mix powdered zinc phosphide into the oats and then add the oil to this mixture, as this procedure may result in accidental poisoning unless this dry mixing can be accomplished in an air-tight container.

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Appendix

Poison formulas for field-rat control with directions for their preparation:

1. *Standard Thallium Sulphate Formula*

(As made up by Pacific Chemical & Fertilizer Company—verified October 10, 1944.)

Rolled oats	1260 pounds (14 bags)
Brown sugar	53 pounds
Add water to make.............	17½ gallons of solution—heated by steam
Thallium sulphate (0.5% or 1–200)	6 pounds, 10 ounces

This formula is the same as that given under the title of "History of Poison Work in Hawaii" but the quantities are doubled.

Method of preparation: The thallium sulphate and sugar are dissolved in hot water. This poison mixture is sprayed into the dry rolled oats as they are stirred and turned over in a closed rotating mechanical mixer. The mixture is then dried by artificial heat at a temperature of 140° F. for seven hours. This reduces the moisture content of the bait to or below that of the original untreated oats.

The changes in this formula from the one published in 1938 (Doty 22, p. 52) consist in leaving out the corn syrup, but adding an equal weight of brown sugar. The water is kept to a minimum to avoid having to evaporate it later, and also to reduce the possibility of some grains adhering to each other in the mixing process before drying.

The water is heated to increase the solubility of the thallium sulphate. The commercial thallium sulphate used in rat poisoning work is in reality thallous salts (Tl_2SO_4). The solubility of thallium sulphate (ous) in water is given in the Handbook of Chemistry and Physics (27th Edition 1943–44) as follows:

4.87 gms. per 100 ml. at 20° C., equivalent to 184.3 gms. per gallon
15.57 gms. per 100 ml. at 99.7° C., equivalent to 590.5 gms. per gallon

Great care should be taken in handling this mixture as thallium is absorbed through the skin. Gloves should be worn if large amounts of poison are being prepared. Only glass, porcelain, or lead containers should be used to hold solutions of thallium sulphate because thallium decomposes in the presence of iron or copper.

2. *Lihue Thallium Sulphate Formula*

Direct mixture of thallium sulphate in oil applied to rolled oats.

Rolled oats	45 pounds
Coconut oil, raw or even boiled linseed oil..	3 quarts
Thallium sulphate (1:150)—135.9 grams...	(.30 pound)

Method of preparation: Place rolled oats in a concrete mixer. Add powdered thallium sulphate to oil and mix thoroughly. Then add the oil and poison suspension to the rolled oats and run the mixer for five minutes. (Courtesy of The Lihue Plantation Company, Ltd.)

3. Zinc Phosphide Formula (preferred)

Pre-dried rolled oats	100 pounds
Zinc phosphide (0.5% or 1–200)...........	½ pound
Mill lime (0.25%)	¼ pound
Corn oil	¾ gallon

Method of preparation: (*a*) The dry zinc phosphide powder and the dry lime powder should be added to the oil and thoroughly stirred.

(*b*) This mixture, which is a suspension of zinc phosphide and lime in oil, is then sprayed or sprinkled into the pre-dried rolled oats. A thorough mixing is essential to give a uniform distribution of the poison throughout the oats. The oats mixture now will have a slightly darkened or sooty appearance caused by the adhering particles of zinc phosphide on the oat flakes. These are visible to the naked eye.

(*c*) The mixture is now ready for use, although it is well to let it stand for an hour or two in order to allow the oil to be absorbed more completely into the oats.

(*d*) Place the poisoned oats in a closed container to keep them as dry as possible until used.

(*e*) If corn oil is not available, "Above Par" or "Mazola" salad oil may be substituted.

Discussion: At Kaeleku the above formula was prepared in a mixing unit consisting of a small motor-driven cement mixer and a paint-spray gun to add the oil-poison-lime mixture to the pre-dried oats. The spray operator should wear a respirator or gas mask for protection against accidental poisoning by breathing the spray vapor.

If the formula is mixed by hand with a hoe in a mixing box, a small sprinkler can be used, but care should be exercised that no large amount of zinc phosphide be allowed to settle out to the bottom of the container as residue and thus materially reduce the poison concentration.

We recommend that the rolled oats to be used as the poison carrier be pre-dried; this can be done over mill boilers or by some other artificial drying method. After adding the oil and zinc phosphide, the oats should be placed in closed containers to prevent the re-absorption of moisture. Much of the undried oats at Kaeleku Sugar Company has shown a hygroscopic moisture content up to 10 per cent, according to R. L. Wold. This is an undesirable amount of moisture because it accelerates the decomposition of the zinc phosphide with the liberation of the obnoxious-smelling phosphine gas.

Poison mixtures made with undried oats tend to smell of phosphine after a few days in storage, whereas mixtures made from pre-dried grain will keep quite well for an indefinite period if kept in a tight, dry container. We have kept samples in the laboratory for more than one year, yet they remained acceptable to rats and were lethal. However, we strongly recommend that poison mixtures be made at frequent intervals (say once or twice a week) and used while still fresh, to insure maximum efficiency in acceptance and killing power.

Under the humid conditions of the unirrigated plantations even the artificially dried grain will absorb moisture, but it should keep in good condition until the rats have had ample time to eat it.

Any oats remaining in the pans after poisoning should be discarded because they

will lose most of their killing power after being damp for several days, even though they were not actually moldy.

We further recommend that the pre-dried oats be screened over an ⅛-inch-mesh screen to remove all small particles. This fine material is unsuitable for use as the poison carrier as it tends to absorb more than its quota of the oil and zinc phosphide and, at the same time, is the least acceptable to the rats. Rats tend to leave the fine-powdered oats in the pans. The screening of the oats becomes almost a necessity when excessive weevil damage has occurred to old supplies of rolled oats.

4. Zinc Phosphide Formula (second choice)

If corn oil, "Above Par" or "Mazola" salad oil are not available, then we would recommend that "white" neutral mineral oil No. 9 or its equivalent* be substituted. In this event, the lime may be omitted. The formula, therefore, would be:

Pre-dried rolled oats	100 pounds
Zinc phosphide (0.5% or 1–200)...........	½ pound
Mineral oil No. 9.........................	¾ gallon
Preparation same as Formula No. 3	

5. Zinc Phosphide Formula (third choice)

If neither of the above formulas can be made, due to lack of the designated oils, then raw linseed oil may be substituted. Since raw linseed oil develops more acidity than corn oil, lime is *more essential,* and should be increased to ½ of one per cent. The resulting mixed poisoned oats should be used promptly and none should be kept in storage.

Pre-dried rolled oats	100 pounds
Zinc phosphide (0.5% or 1–200)...........	½ pound
Mill lime (0.5% or 1–200)................	½ pound
Raw linseed oil	¾ gallon
Preparation same as Formula No. 3	

6. Zinc Phosphide on Coconut Cubes Formula

Fresh coconut cut in half-inch cubes (5 lbs.)	2268 grams
Mill lime (0.33%)	75.5 "
Zinc phosphide (0.33% or 1:300)..........	75.5 "

Method of preparation: Only fresh, mature coconuts containing milk should be used. The coconut should be cut into approximately half-inch cubes and placed in a closed container, or a small cement mixer. The material should be shaken or tumbled for about five minutes to bruise the coconut cubes and bring the juice to the surface. Then the zinc phosphide and lime, after being mixed together, are added, followed by another five minutes of shaking or tumbling to allow the coconut juice to mix with these materials and cause them to adhere to the cubes. If this bait is to be used immediately after mixing, it must be protected from rain. However, two or three hours of drying in the sun will increase its usefulness by causing the lime and zinc phosphide coating to harden, forming a protective coating which resists rain and handling to a remarkable degree.

The coconut bait should be scattered in the field the same day that it is pre-

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*Standard Oil Company's white neutral No. 9 has a viscosity of 185–195 at 100° F.

pared. If it must be kept overnight it should be thinly spread on a tray or canvas. Untreated fresh diced coconut should not be kept overnight as it sours very quickly.

Antidote for Zinc Phosphide Poisoning

In the case of accidental poisoning by zinc phosphide, F. E. Garlough of the Fish and Wildlife Service, Department of Interior, recommends that the following treatment be given:

1. Give an emetic of mustard.
2. After vomiting has ceased, completely dissolve one tablet (5 grns.) of potassium permanganate in a glass of warm water and take.
3. After 10 minutes, give ½ teaspoonful of copper sulphate in a glass of water.
4. Fifteen minutes later, give 1 tablespoonful of epsom salts in a glass of water.

Give demulcent drinks, avoid all oils. Call a doctor.

We suggest that this information be a part of the label on any supply of zinc phosphide kept by plantations.

7. *Old Bait Formula*

This modified whole-wheat formula may be used with rolled oats by adding any of the following poisons: thallium sulphate, arsenic oxide, arsenic pentoxide, or strychnine alkaloid.

	Formula	1/10 of formula	1/20 of formula	1/40 of formula
Starch	9.0 grams	.9 gram	.45 gram	.23 gram
Water*	354.0 cc.	35.4 cc.	17.7 cc.	9.0 cc.
Baking soda	28.4 grams	2.84 grams	1.42 grams	.71 gram
Raw sugar (add water to make syrup)	176.0 grams	17.60 grams	9.0 grams	4.5 grams
Glycerine	24.0 grams	2.4 grams	1.2 grams	.6 gram
Saccharine	2.8 grams	.28 gram	.14 gram	.07 gram
Tl_2SO_4 or As_2O_3 or As_2O_5 or Strychnine	51.64 grams (0.5% or 1–200)†	5.16 grams	2.58 grams	1.30 grams
Rolled oats	10328.0 grams (22¾ lbs.)	1032.8 grams	516.4 grams	258.4 grams

*Amounts of water may be increased for the small portions to facilitate mixing.

†Note that the figures are all on basis of 0.5% or 1–200. However, arsenic is generally used in a higher concentration; many workers recommend five per cent. Strychnine may be used in much lower concentrations, *i.e.*, 1 to 300.

Method of preparation: The starch is added to cold water and heated to boiling until the starch clears (about 15 minutes), stirring almost constantly. Add the baking soda and stir. Dissolve the raw or brown sugar and saccharine in warm water and add to the starch mixture and bring to a boil. Add glycerine and stir. Dissolve (except when using As_2O_3) the poison material in warm water, and add it to the starch sugar mixture while still hot and stir. The final poison mixture is added to small lots of rolled oats in proportionate amounts and thoroughly mixed. The treated grain is spread on trays for immediate drying by artificial heat.

When thallium is the poison used, only glass, porcelain, or lead containers should be used to hold the solutions.

8. *Old Strychnine Formulas*

Lantz (45, p. 250) suggested strychnine formulas as follows:

(*A*) Strychnin (Alkaloid) Formula. — Mix thoroughly 1 ounce of powdered strychnin (alkaloid), 1 ounce of common baking soda (bicarbonate) and one-eighth ounce of powdered saccharin. Put the mixture in a tin pepperbox and sift it gradually over 30 pounds of crushed oats in a metal tub, mixing the grain constantly so that the poison will be evenly distributed. Put out the poisoned grain about rat burrows or runs, but not in piles of more than a teaspoonful.

(*B*) Strychnin (Sulphate) Formula. — Dissolve 1 ounce of strychnin (sulphate) in a pint of boiling water. Dissolve a heaping tablespoonful of dry laundry starch in a little cold water, add it to the strychnin solution, and continue to boil for a few minutes until the starch is clear. Add a scant teaspoonful of saccharin or a cup of thick sirup to sweeten the paste and stir thoroughly. Pour this mixture while hot over 12 quarts of clean oats in a metal tub and mix until all the grain is coated. Before using let the grain stand until the coating dries. Occasional stirring will hasten the drying. Scatter the grain near rat burrows or runs.

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THE HAWAIIAN PLANTERS' RECORD

H. L. LYON, *Editor*

EXPERIMENT STATION STAFF

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